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FOUR YEARS OF NIGHT VISION GOGGLE DIOPTER EYEPIECE RESEARCH AND FIELD STUDIES WITH AFSOC AIRCREW (2000-2004)

Share-Dawn P. Angel
Bruce J. Baldwin
Douglas L. Franck

HUMAN EFFECTIVENESS DIRECTORATE
WARFIGHTER INTERFACE DIVISION
WRIGHT-PATTERSON AFB OH 45433-7022

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Human Effectiveness Directorate
Warfighter Interface Division
2255 H Street
Wright-Patterson AFB OH 45433-7022

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FOR THE COMMANDER

//Signed//

LEE D. SHIBLEY, Lt Col, USAF
Deputy Chief, Warfighter Interface Division
Air Force Research Laboratory

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13. ABSTRACT *(Maximum 200 words)*

The US Air Force aircrews are some of the most skilled and highly experienced night vision goggle (NVG) wearing aircrew in the world. In the 1990's with AN/AVS-9 (F4949) aircrews have become used to having continuously adjustable eyepiece diopter settings. Continuously adjustable eyepiece settings are not in the design of the newest NVG that is in the transition phaze of being fielded: the Panoramic Night Vision Goggle (PNVG) has a 95-degree horizontal field-of-view, achieved with two channels per ocular with an image intensifier each. These studies in this tech report address several issues in determining the best solution to provide acceptable range of eyepiece settings for a fixed focus NVG. The first series of studies were surveys to determine what fixed setting should work best, we examined what 97 AFSOC aircrew members were preflighting their NVG eyepieces, we addressed how repeatable aircrew were at setting their eyepieces, we then addressed how aircrew would tolerate flying at either -1.0 D or -0.50 D. We wanted to see how acceptable the use of snap-on lenses would be to aircrew. Aircrew members did give a favorable response to the use of snap-on lenses. We then examined the issue of how many snap-on lenses should be necessary for the majority of the user population. From this study it was determined that the majority of aircrew could work with a total of 3 diopter settings: -0.25 D, -1.0 D, and -2.0 D. Custom snap-on lenses could be made for the few that could not work with the three choices. Some of the individuals that could not find the three choices workable, may have needed to be refracted, and the fact noted from the first study that aircrew are not very repeatable in setting their eyepiece settings that the final study was created to see what visual acuity aircrew would get with different diopter settings.

14. SUBJECT TERMS
diopter, night vision goggles, field-of-view, AN/AVS-9, F4949, Panoramic Night Vision Goggle, Integrated Panoramic Night Vision Goggle, ANV20/20, special operations squadrons, snap-on lenses, aircrew

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NVG eyepiece focus (diopter) study

Share-Dawn Angel
Air Force Research Laboratory
Wright-Patterson AFB OH 45433-7022

Abstract

Technology is advancing to the point where night vision goggle designs being developed have wider fields of view to help achieve an increase in situational awareness. The appropriate diopter setting for the eyepiece of these goggles needed to be determined. Aircrew members were surveyed to determine the range of diopter settings they were using. In order to determine what fixed setting would work the best, two diopter settings were chosen (-1.0 and –0.5) to preset aircrew members' goggles. The aircrew flew with these presettings and then filled out a 14-question survey about the diopter settings.

Keywords

Diopter, dioptometer, field of view, night vision goggles, AN/AVS-9, Panoramic Night Vision Goggle (PNVG), Integrated Panoramic Night Vision Goggle (IPNVG), eyepiece diopter setting.

1. Introduction

Night vision goggles (NVGs) were developed by the US Army, but the US Air Force first used them for flying, in the early 1970's, as a temporary aid for helicopter pilots.[1] The majority of currently fielded U.S. Air Force aircrew goggles are the AN/AVS-9 (Figure 1), which have a 40-degree field of view (FOV) and adjustable eyepieces. A large survey of U.S Air Force NVG users in 1992 and 1993 revealed that an increased FOV was the number one enhancement desired by aircrew, with increased resolution a close second.[2] The current prototype goggle, the panoramic night vision goggle (PNVG) (Figure 1) has 100-degree horizontal by 40- degree vertical FOV, but it has a fixed-focus eyepiece. Currently in development, the Integrated Panoramic Night Vision Goggle (IPNVG) will have a 95-degree horizontal by 38-degree vertical FOV, and it may also have a fixed-focus eyepiece.

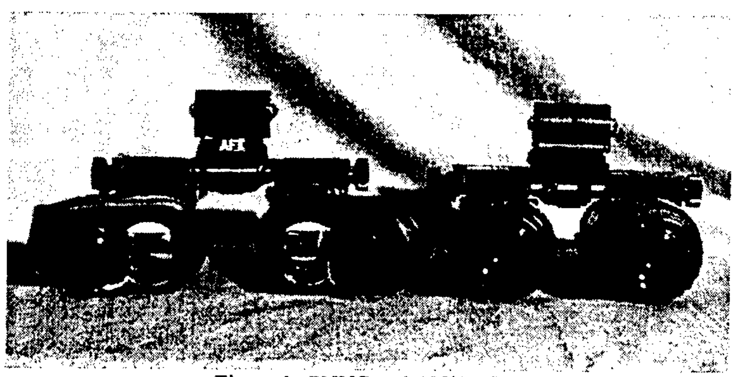

Figure 1. PNVG and AN/AVS-9

Three studies were performed to help determine what fixed diopter setting of the eyepiece will work for most aircrew. These studies were conducted at several Special Operations Squadrons in Ft. Walton Beach, Florida. This location was selected because of the large number of highly experienced night vision goggle trained aircrew in the Special Operations community. The first study investigated the diopter setting to which aircrew were adjusting their own goggles just prior to their missions. A second study addressed how repeatable aircrew were at setting their eyepieces following current NVG preflight protocol. The third study addressed how aircrew would tolerate a fixed-focus eyepiece.

Further author information –
Share.Angel@wpafb.af.mil; http://www.hec.afrl.af.mil; telephone: 937/255-8894 fax: 937/255-8366

2. Study I

Study I was conducted at 5 US Air Force Special Operations Squadrons in the Ft Walton Beach, Florida area. It occurred in August 2000 over the course of a week. The purpose was to measure and record as many eyepiece settings from qualified NVG aircrew as possible.

2.1 Methodology

2.1.1 Participants: Ninety-five aircrew participated in the diopter setting study. There were 94 males and 1 female. Ages ranged from 21 to 59, with a median of 33. The 4th, 5th, 8th, 9th, and 711th Special Operations Squadrons participated. These squadrons were selected for their large numbers of highly NVG qualified aircrew. There were 32 pilots, 12 navigators, 20 loadmasters, 14 flight engineers, 8 gunners, 8 radio operators, and 1 life support technician.

2.1.2 Apparatus: The aircrew used their squadron's own goggles for this study. There are three power source mounts for the goggles and three types of power sources/goggle attachments: hand-held battery pack, opera mount, and the helmet battery pack. The helmet mount has a battery pack in the back of the helmet to power the goggles. The hand-held battery pack is small and lightweight. The opera mount is also a handheld power source, but much bulkier and looks like a helmet battery pack on a stick. The pilots and loadmasters use the helmet mounts. The remainder of the aircrew would typically use either the hand-held battery pack or the opera mount. These goggles are pre-flighted by aircrew members using the ANV-20/20 (Hoffman 20/20). The ANV-20/20 (Figure 2) is a portable case containing optics with a resolution chart, which allows aircrews to adjust their goggles to infinity focus.[3] An investigator used a hand-held dioptometer (Figure 3) to read the diopter settings off the eyepieces of the NVGs after they were set by the aircrew member. A diopter is an expression of the eyepiece focus described as the reciprocal of the image distance.[4]

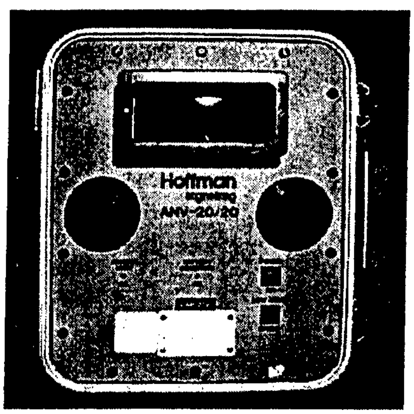

Figure 2. ANV-20/20.

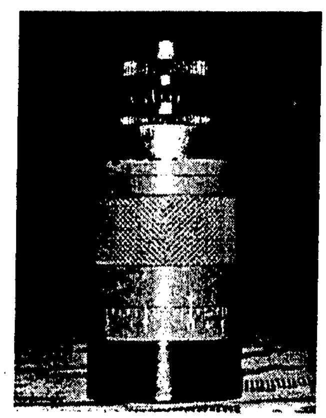

Figure 3. Dioptometer.

2.1.3 Procedure: The aircrew preflighted their own goggles as they normally did for their night missions. Preflighting is a term aircrew use to describe the focusing of the night vision goggle, typically done shortly before departing on their flying mission. After the crewmember adjusts the goggles for the distance between the crewmember's eyes, the crewmember looks into the ANV-20/20, sees a resolution chart, grossly adjusts the objective lenses by focusing on the coarser lines on the resolution chart, then adjusts one eyepiece at a time. The crewmember focuses the eyepiece by first turning the eyepiece counterclockwise which will blur the image in the positive diopter direction. Next, the crewmember turns the eyepiece clockwise until the image is clear. For that ocular, the crewmember then returns to the objective lens and "fine tunes" the objective lens so that the image of the fine lines on the resolution chart come into clarity. There are several procedures for recording visual acuity. Some aircrew members use the high-light level acuity/low-light level acuity of both eyes, and some aircrew record the visual acuity of each eye individually. We specified only that the aircrew record the acuity, as they would normally do in their squadron's logs. The goggles were then handed to the investigator, who read the left ocular diopter setting to the nearest 0.05 diopter (D) and recorded it on a data sheet. This method was repeated for the right ocular.

The eyepiece of the dioptometer was calibrated for the investigator. The investigator first sets the objective lens to 0 D. Next the investigator must find an object greater than 200 feet away (Figure 4). Looking through the dioptometer, the investigator rotates the eyepiece counterclockwise to blur the image and then rotates the eyepiece clockwise until the image is crisp and clear.

Figure 4. Focusing the dioptometer.

To read the diopter setting of the goggles, the investigator, in a darkened room, keeps the eyepiece of the dioptometer fixed. The investigator puts the objective piece of the dioptometer close to the eyepiece of the goggle. While focusing on the scintillations, the investigator rotates the objective lens of the dioptometer, counterclockwise (to blur the scintillations), and then clockwise to bring the scintillations into the best possible focus. Scintillations are the "noise" of the image intensifier tubes, which appeared as sparkles.[5] The diopter value was then recorded. All goggles were read from left ocular to right ocular. The aircrew member determined a visual acuity value by looking at the resolution chart in side the ANV-20/20. The visual acuity of the aircrew member was recorded on the data sheet.

2.2 Results

There were 95 aircrew participants who preflighted their goggles. The diopter settings of the 190 oculars (95 aircrew X 2 oculars) ranged from –3.9 to +0.5 D with a median of –1.05 D. Figure 5 shows the estimated Weibull distribution (see Appendix for a description of Weibull distribution) for the 190 oculars.

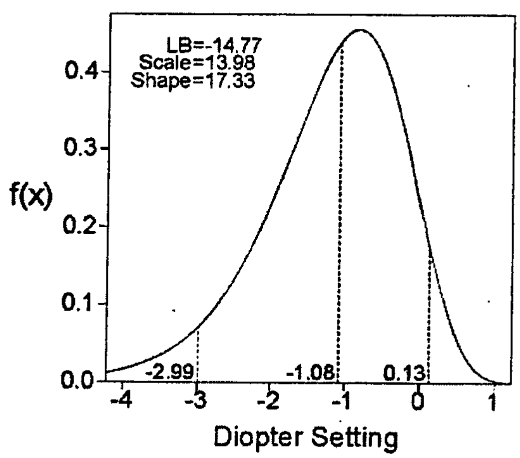

Figure 5. Estimated Weibull distribution for 95 aircrew. Referenced values are 5th, 50th and 95th percentiles.

3. Study II

Study II was conducted at the same time as Study I. The purpose was to see how consistent these highly trained aircrew were at preflighting their goggles.

3.1 Methodology

3.1.1 Participants: Eighteen aircrew members participated in the second study. There were 8 pilots, 3 loadmasters, 2 flight engineers, 3 gunners, and 2 radio operators. Ages ranged from 21 to 45 years, with a median of 32 years.

3.1.2 Apparatus: The apparatus in this study was the same as that used for Study I.

3.1.3 Procedure: The same procedure was used as in Study I, except each crewmember preflighted his/her goggles a total of five times. After the goggle was handed to the investigator, who read the settings of both oculars with the hand-held dioptometer, the investigator reset the eyepiece ocular to zero and handed the goggle back to the aircrew member.

3.2 Results

Figure 6 contains the diopter settings per aircrew individual for each of the five repetitions. The repeatability limit (rL) was defined as: approximately 95% of all pairs of adjustments from the same aircrew individual and same ocular should differ in absolute value by less than the rL. There were some individuals, such as number 15, who were much more variable than other individuals. Since some of the non-pilots appear to be less experienced than the pilots in adjusting their goggles, it was decided to utilize just the pilots (numbers 1-8) in computing the rL. The rL of the pilots was 1.2 D.

The pooled standard deviation of the left and right oculars for Figure 6 was determined for each aircrew number. There was not a significant correlation between the age and pooled standard deviation of the 18 aircrew ($R = 0.30$, $p = 0.2574$). This implies that there was not a relationship between an individual's age and the spread of his/her five settings.

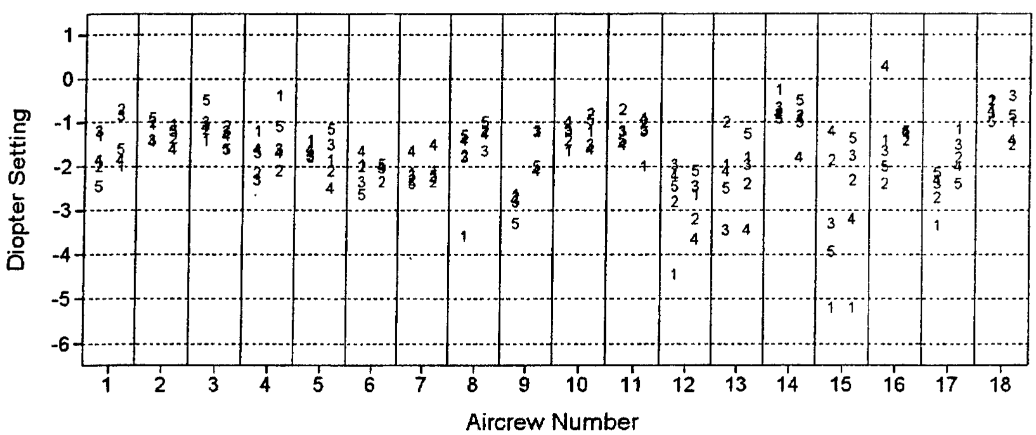

Figure 6. Diopter values for each crewmember, ocular, and adjustment are in the above figure. Within each aircrew number's window, the left ocular values are on the left and the right ocular values are on the right. The legend is the value of the adjustment (1-5). Aircrew numbers represent aircrew positions as follows: 1-8 pilot, 9-11 loadmaster, 12-13 flight engineer, 14-16 gunner, 17-18 radio operator.

4. Study III

The main purpose of Study III was to find out how aircrew liked certain fixed diopter settings. Since the median diopter setting from the first study was –1.05 D, it was decided to use –1.0 D as a starting eyepiece setting. When many of the aircrew felt that –1.0D was unacceptable, a diopter setting of –0.5 D was selected as a second setting to test.

4.1.1 Participants: Ninety aircrew participated in the November 2000 eye focus part of Study III. There were 41 pilots, 17 navigators, 12 loadmasters, 12 flight engineers, 4 gunners, 2 radio operators, and 2 flight surgeons. These crewmembers came from the 4th, 5th, 8th, 9th, 20th, and 711th Special Operations Squadrons.

Seventy-seven crewmembers filled out the questionnaire. There were 34 pilots and 43 non-pilots, consisting of 2 women and 75 men with ages ranging from 24 to 57 years and a median of 36 years. Forty-three aircrew flew with the –1.0 D setting and 34 aircrew flew with the –0.5 D setting. There were 4 individuals who responded to both the –0.5 and –1.0 D setting questionnaires. The NVG flying hours of all aircrew ranged from 15 to 3000 hours with a median of 500 hours.

4.1.2 Apparatus: The equipment was the same as in Study I, except there was a questionnaire. A logbook was used instead of data sheets and the eye focus aircrew settings were performed on a calibrated pair of goggles from AFRL. The questionnaire included background information such as name, sex, squadron, age, aircrew position, and NVG flying hours. Further questions focused on their flight with a fixed eyepiece. These questions included: (1) whether they adjusted the preset goggles in flight, and if they adjusted the preset goggles and why, (2) how long they wore the goggles continuously in-flight, and if they looked away from their goggles for an extended period, why, and for what duration, (3) whether they preferred their current goggle with the adjustable eyepiece focus or a fixed-focus goggle with a wider FOV, (4) six questions with rating scales for finding their opinions on the chosen fixed settings, and (5) a comments section at the end. Although the questionnaire had 14 questions, only a couple are considered for analysis here. We have analyzed an abridged version covering the sex of the aircrew member, the age, the aircrew member's NVG hours, briefly covering whether they preferred their own setting or the preset eyepiece, which was better with regard to eyestrain, blurriness, situational awareness, and threat detection.

4.1.3 Procedure: For this study, aircrew preflighted a pair of laboratory-owned and eyepiece-calibrated AN/AVS-9. This goggle was handed to the investigator who read the settings to the nearest 0.25 D and recorded it in the logbook. The aircrew member's flight goggles were previously preset to either –1.0 or –0.5 D using the hand-held dioptometer. The aircrew member used the ANV-20/20 to ensure that their visual acuity was acceptable by the aircrew member's own standards for flying. The specific visual acuity that is acceptable depends on the particular goggle. They recorded their visual acuity in our logbook. They flew their scheduled night sortie. When they returned to the squadron, they filled out the questionnaire.

4.2 Results

There were 185 aircrew total from (Study I and Study III) that were used for diopter setting analysis.
Their ages ranged from 20 to 59 years, with a median of 34 years. Seventy-three pilots and 112 non-pilots participated, including 7 women and 178 men.

The settings of the 370 oculars (185 aircrew x 2 oculars) ranged from –3.9 to +0.5 D with a median of –0.90 D. Figure 7 shows the estimated Weibull distribution for the 370 oculars.

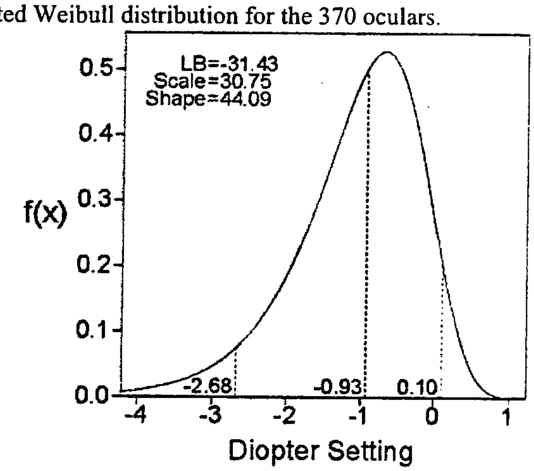

Figure7. Estimated Weibull distribution for all aircrew (referenced values are 5th, 50th, and 95th percentiles).

Figure 8 shows separate estimated distributions for the pilots and non-pilots. The parameter estimates for pilots only were: LB=–13.91, Scale=13.06, and Shape=18.11. The average of the left and right diopter settings was determined for each aircrew individual. There was a significant difference in these averages ($p = 0.0216$) between the pilots ($N = 73$) and other aircrew ($N = 112$) using the Wilcoxon rank sum test.

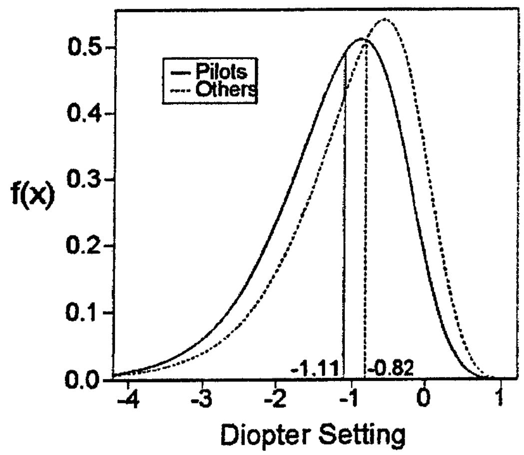

Figure 8. Estimated Weibull distributions for pilots versus others (reference values are 50th percentiles).

Ocular disparity is the difference in diopter settings between the right and left eyepiece. The absolute difference in ocular disparity ranged from 0 to 2.5 D with a median of 0.4 D. Of the185 aircrew, approximately 29% had ocular disparity greater than 0.5 D.

Table 1. This table shows a summary of the comparison of fixed settings vs. the aircrew member's personal settings. We compared fixed focus of either –1.0 D or –0.5 D to adjustable focus. The fixed settings were compared to the aircrew member's personal setting, and how it affected: the mission, reducing eyestrain, situational awareness, reducing blurriness, and threat detection.

Table 1. Percent of aircrew rating effect of fixed eyepiece setting the same, somewhat better, or much better compared to personal setting.

Effect of Fixed Eyepiece Setting	Percent Same or Better	
	-1.0 D (N=43)	-0.5 D (N=34)
compared to personal	60	47
mission accomplishment	86	71
reducing eyestrain	76	53
reducing blurriness	51	38
situational awareness	86	67
threat detection	85	67

5. Discussion/Analysis

The Study I excursion was a data gathering mission to determine to what diopter values aircrew were setting their goggle eyepieces. The data were examined to determine the best possible single diopter setting which might work for the NVG using community. The median setting of –1.05 D resulted in a starting fixed setting of –1.0 D. We were also able to see that the settings ranged from –3.9 to +0.5 D. How variable the aircrew were in adjusting their oculars was another concern, since with a fixed-focus aircrew would not have an option of different diopter settings in each ocular. Twenty-nine percent of setting disparities were over 0.5 D, possibly indicating that refresher courses in NVG focusing could be helpful. This is important because a person's eyes do not accommodation sufficiently to differential stimuli greater than 0.5 D.[6] Suppression

does not occur when the diopter difference between the two eyes is less than about 0.5 D.[6] While people may have different diopter requirements in each eye, they should have been corrected to 20/20 Snellen acuity, and most people do not have large differences in their eye prescriptions. This brings up the concern that a significant percentage of the aircrew were likely adding eyestrain and accommodating with both eyes inappropriately. Of course, a fixed-focus eyepiece would alleviate this issue for most aircrew.

Looking at the 18 aircrew that performed the repeatability study, there are several issues to be discussed. The repeatability was calculated for the pilots. The pilots had a repeatability limit of 1.2 D; so for an individual pilot, focusing one eye could be 1.2 D different from one preflight to another. This raises several potential issues. It is possible that individuals are not truly sensitive to the eyepiece adjustment of their goggles. If we were to take an aircrew member and set his goggles within 1.2 D of his personal eyepiece setting, this should be tolerable. The aircrew member did not wear these setting for more than the time required to focus in the ANV-20/20. While they may have been able to achieve an acceptable level of visual acuity, it is possible that some of these settings may have caused the aircrew eyestrain during flight.

It was observed that the pilots and loadmasters were able to focus their goggles with a narrower range compared to the other aircrew members. Their use of a helmet mount for the goggle may play a role in their ability to set eyepieces within a tighter range. With goggles anchored at a fixed distance from the individual's eyes, their hands are not needed to support the weight of the goggles during the focusing procedure. For mission safety, both pilots and loadmasters must be able to see more clearly, with better visual acuity, and less eyestrain than other aircrew members. The other aircrew members do not usually use their helmets to mount their goggles; instead, they typically use the opera mount or the battery pack to power the goggles. Neither of these devices can offer the same stability as the helmet mount. If supporting the weight of the goggles, an aircrew member's hands may become less steady from one eye focusing to the next. In addition, the distance of their eyes to the goggle would likely differ from each eye focusing. Other members do not wear the goggles as much in flight, so they may not take the same time to ensure the most clear eye focus. It can be noted that some of the greatest differences in ocular disparity for goggles were from the gunners; this could be because, in the aircraft, they do not wear the goggles very often or for very long on their missions.

If one were forced to pick an acceptable diopter setting, one could draw a line through Figure 6 cutting through the adjustment range of most of the 18 aircrew. This would be done with the assumption that all settings within each individual's range would be acceptable for that aircrew member and not cause too much eyestrain. When we pass such a line through –1.0 D, it essentially passes through all but 3 aircrew members' settings. Pilot #6 and pilot #7 were within 0.5 D of this line, so they may be able to find this setting acceptable. If –0.5 D were selected, 10 aircrew would likely not find this setting acceptable. The Study I and Study II analyses helped us select –1.0 D as a starting setting for Study III.

The settings from Study III were combined with the Study I settings, yielding an even clearer picture of where aircrews were setting their goggles. The estimated Weibull distribution for all the aircrew combined showed the 50^{th} percentile to be –0.93 D. It has been reported that the optimum power is between –1.0 and –0.5 D by Pearce et. al.[7] and between –2.25 and –1.0 D by Mouroulis and Woo.[8] The pilots had a left shift in their diopter setting plot. Pilots were approximately –0.3 D (50^{th} percentile of –1.11 D) more minus from the rest of the aircrew (50^{th} percentile of –0.82 D). This could be because they tried to achieve the sharpest visual acuity possible. These results are remarkably similar to an Air Force Research Laboratory technical report on an 1993 survey in which an average eyepiece setting of –1.1 D was observed.[4] This result, a setting around –1.0 D, has also been supported in the literature indicating that acuity is maximized for a target at a distance corresponding to about 1.0 D of accommodation.[9] In a short-term wear study conducted by Gleason and Riegler, it was found that the best eye focus was –1.0 D, with this setting yielding the best average visual acuity across all conditions and subjects.[4]

Examining the questionnaire data, it appears that the –1.0 D fixed setting was less distasteful to the aircrew than the –0.5 D fixed setting; however, both the –1.0 and –0.5 D fixed settings were worse than personal settings for many of the aircrew. The greatest concern of the aircrew with the fixed setting appeared to be blurriness.

6. Conclusion

Is fixed focus or adjustable focus best for night vision goggles? Single-focus eyepieces are simpler, lighter, and cheaper because focus mechanisms are not needed; shorter single-focus eyepieces would reduce a goggle's overall length, bringing the center-of-gravity closer to the head while maintaining eye relief.[4] It has not been possible to find a perfect setting for all users, but –1.0 D may be acceptable to a large number of aircrew. The aircrew have become used to the ability to set their own goggles. Since aircrew members desire as much control over their missions as possible, it is likely that they would prefer to maintain this if possible. The views of the aircrew have been positively supported in the literature, that visual acuity is always better with an adjustable-focus eyepiece, than with a fixed-focus eyepiece.[10] Recent developments <u>may</u> permit a limited range of eyepiece adjustable focus for the integrated panoramic night vision goggle. This would likely be a 2 D range. Based on modeling, an eyepiece having a –0.25 to –2.25 D range is probably best. According to the Weibull distribution, this range would not cover approximately 25% of aircrew. Approximately 9% would want more negative adjustment, and approximately 16 percent would want more positive adjustment.

However, given people's ability to accommodate, if we assumed aircrew could accommodate ±0.5 D, the relative range would span +0.25 to –2.75 D, which would exclude only about 7% of the aircrew. Approximately 5% of ocular settings would be more negative than –2.75 D and approximately 2% would be more positive than +0.25 D. Also, when designing an optical product there are certain production tolerances that are allowed. We would not want the margin of error to be shifted in the more positive direction. If the settings were more positive than 0 D in the most positive direction, and if there was only a 2 D span of settings, the crewmembers that required the more negative settings would not be satisfied.

If adjustable lenses do not come into production, we may need to provide "snap on lenses"on a fixed focus eyepiece. These "snap on lenses" would be additional lenses that would attach to the eyepiece and would have minus or plus power. If we had a fixed eyepiece, based on the data we would likely choose –1.0 D. We might also provide a –1.0 snap on lens that would provide a total –2.0 D, which would only have approximately 13% of aircrew requiring more negative power. A +0.75 D lens would be utilized to provide a net –0.25 D. This would leave only approximately 16%of people to the right of this range who would require a more positive setting. These people that would be out of the range may not be satisfied due to the possibility of eyestrain, fatigue and possibly blurriness.

If we must have a fixed eyepiece, we would likely select –1.0 D. This appears to be the best setting. Snap on lenses would help meet the needs of the aircrew that require it. If variable focus becomes available, it will likely be well received by the aircrews and other NVG users. It would be advisable to be able to have a range that would effectively include crewmembers that would require +0.25 to –2.75 D. If a limited adjustable eyepiece can be designed with future goggles, then this should be undertaken, since there is no one diopter setting that will best serve all of our goggle users.

Acknowledgments

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Appendix

Weibull Distribution

Following is a description of the Weibull distribution.[11] This distribution was used to model diopter settings.

$$f(x) = \left(\frac{\beta}{\alpha}\right)\left(\frac{x-x_o}{\alpha}\right)^{\beta-1} e^{-\left(\frac{x-x_o}{\alpha}\right)^{\beta}} \quad \text{where } 0 < \alpha \text{ and } 0 < \beta$$

α = scale parameter, β = shape parameter, x_o = lower bound (LB)

$$F(x) = 1 - e^{-\left(\frac{x-x_o}{\alpha}\right)^{\beta}} \quad \text{transforms to: } \mathrm{Ln}\{-\mathrm{Ln}[(1-F(x)]\} = -\beta * \mathrm{Ln}(\alpha) + \beta * \mathrm{Ln}(x - x_o)$$

$$\text{regression equation: } Y' = \mathrm{Intercept} + \mathrm{Slope} * X'$$

$$\text{so: } \beta = \mathrm{slope}, \text{ and } \alpha = e^{-\left(\frac{\mathrm{Intercept}}{\beta}\right)}$$

Parameter estimates are obtained by transforming the cumulative distribution F(x) to a form that can be used in linear regression. In the transformed cumulative distribution, estimates of F(x) are the cumulative proportion at every level of X from the observed data. The lower bound is determined by using the X_O value that makes the transformed cumulative distribution the most linear (i.e., yields the highest correlation). The scale and shape parameter estimates are determined from the intercept and slope estimates of the linear regression.

It is possible for the lower bound (X_O) to be an unattainable value. For example, absolute differences must be non-negative yet X_O may be negative. This negative lower bound is necessary to obtain the best fit of the transformed cumulative proportions. A desired goal in fitting the Weibull distribution is for the percentiles of the estimated distribution to match closely with the percentiles of the data. What should occur is the area under the curve ≤ 0 should closely match the cumulative proportion at $X = 0$ from the data.

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Brief Biography

Share-Dawn Angel was commissioned into the US Air Force in 1993. Before coming to the Air Force Research Laboratory at Wright-Patterson AFB, OH, she was a flight surgeon attached to the 9th Special Operations Squadron, Eglin AFB, FL. She has over 50 hours of NVG time in MC-130P Combat Shadows. She has a BS degree in Biology from George Mason University, Fairfax, Virginia, in 1993, and is a 1993 graduate of AFROTC from College Park, University of Maryland in 1993. She earned her medical degree from the Uniformed Services University, Bethesda, MD in 1997. In 1998, she completed a General Surgery Internship at Keesler Medical Center, Keesler AFB, MS.

Aircrew acceptance of fixed-focus eyepieces for night vision goggles

Share-Dawn P. Angel and Douglas L. Franck

Air Force Research Laboratory
Wright-Patterson Air Force Base, Ohio 45433-7022

ABSTRACT

The wide field of view night vision goggles (WNVG) are the next generation of night vision goggles (NVG). They have a significantly increased horizontal field of view and a weight similar to the current AN/AVS-9, which only has a 40 degree circular field-of-view (FOV). Due to complicated optics and weight issues, the WNVG will have a fixed-focus eyepiece; this is different from the AN/AVS-9 (Figure 1), which has a continuously adjustable +2.0 to -6.0 diopter (D) range for each eyepiece. Site visits were made to several Special Operations Squadrons to survey aircrew members about the WNVG with a fixed-focus eyepiece and optional clip-on lenses. This paper addresses aircrew acceptance of the use of snap-on/helper lenses in place of continuously adjustable eyepieces.

Keywords: diopter, night vision goggles (NVG), field of view (FOV)

1. INTRODUCTION

NVGs used in military aviation have ranged from 30 to 45 degrees circular FOV with a typical NVG FOV of 40 degrees (Figure 2).[1] A 1993 survey of United States Air Force NVG users determined that the biggest improvement desired was an increase in the FOV of the NVGs but without sacrificing resolution.[2] Since image intensifier tubes have a fixed number of pixels any effort to expand the FOV would result in lower resolution because the same number of pixels would be spread over a larger angle. Therefore, the only way to meet the warfighter needs of increased FOV without resolution reduction was to increase the number of image intensifier tubes. The WNVG used four image intensifier tubes to provide the wearer with a larger viewing field, versus the two image intensifier tubes in current NVGs.

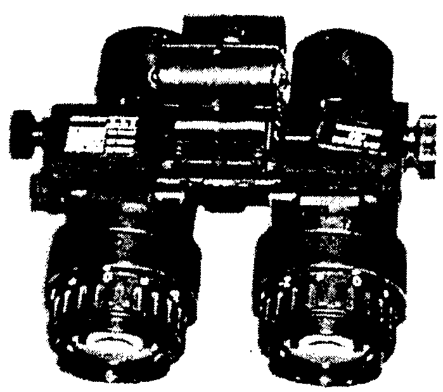

Figure 1: AN/AVS-9

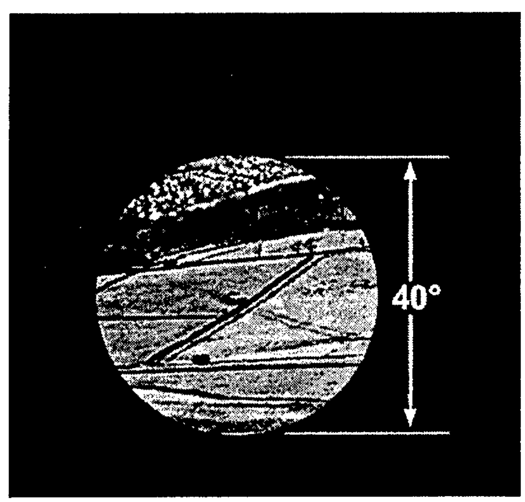

Figure 2: Simulated 40° NVG FOV

For Author Information –
Share.Angel@wpafb.af.mil; http://www.hec.afrl.af.mil; telephone: (937) 255-8894; fax (937) 255-8366

The WNVG has a binocular overlap in the two center channels. Unlike previous attempts to increase FOV, the WNVG has not significantly increased weight or significantly reduced resolution. The WNVG was able to maintain comparable weight and resolution to the AN/AVS-9 goggles by using smaller image intensifier tubes versus the standard 18-mm format image intensifier tubes (Figure 3).

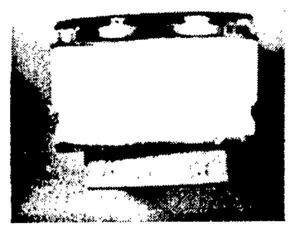

Figure 3: 18 mm Image Intensifier Tube

The WNVG was supposed to have a fixed-focus eyepiece set at -0.75 diopter (D) versus a continuously adjustable eyepiece for the standard NVG. However, the WNVG eyepieces did not achieve the -0.75 D because of the impossibly tight tolerances required. Most of the WNVG eyepieces have diopter settings closer to zero (see Figure 5). The WNVG eyepiece has two pieces of glass bonded together at an angle to allow a view through each tube. This bonding of the glass prevents the operator from individually changing each eyepiece. There was a significant weight penalty and additional optics complexity that made it impractical to include a continuously adjustable focus eyepiece. The follow-on WNVG also has a fixed-focus eyepiece of -1.0 D, and a snap-on/helper lens option is needed to support the entire operator population. A study was initiated using the WNVG to determine if a helper lens added to the eyepiece to change the diopter setting can provide the operators adequate resolution and be acceptable to the aircrew members.

2. METHODOLOGY

Participants: Ten male aircrew members participated in the diopter setting study. Ages ranged from 21 to 45, with a median of 34.5. There were six pilots, two loadmasters, one gunner, and one flight engineer. All participants had significant amounts of NVG flight time (see Table 1). The WNVG with the helper lenses were flown on fixed wing and helicopter aircraft. Each aircraft has a different mission, which requires different NVG performance to successfully complete a task. Aircrew members with different backgrounds participated in the study.

Table 1. Aircrew Background: The 'Code' was a combination of aircrew number and position. Aircrew 5-LM did not fill out a questionnaire. Aircrew 1-P and 3-AG wore glasses.

	Aircrew				Flying Hours	
WNVG	**Code**	**Position**	**Aircraft**	**Age**	**Total**	**NVG**
1	1-P	Pilot	Fixed Wing	39	3100	300
	2-P	Pilot	Fixed Wing	32	2600	300
	3-AG	Aerial Gunner	Helicopter	33	1000	650
	4-FE	Flight Engineer	Fixed Wing	35	4300	400
	5-LM	Loadmaster	Fixed Wing	33	1300	500
2	6-P	Pilot	Fixed Wing	33	2100	400
	7-P	Pilot	Helicopter	33	3500	500
	8-P	Pilot	Fixed Wing	41	4700	1000
	9-P	Pilot	Fixed Wing	45	5500	700
	10-LM	Loadmaster	Fixed Wing	21	627	112

Apparatus: The aircrew used the WNVG for this study. They had their own AN/AVS-9 with them during flight, should they desire to switch back anytime during the flight. The aircrew members all used the helmet-mounted battery pack as their source of power for the goggles. Aircrew members using the ANV-20/20 NVG tester pre-flighted the goggles. The ANV-20/20 has a portable case containing optics with a resolution chart, which allows aircrews to adjust their goggles to infinity focus.[3] Two sets of snap-on/helper lenses (See Figure 4) was available for use with each WNVGs. One set helper lens was made from -1.00 D ophthalmic lenses and the other set was made from -1.75 D ophthalmic lenses.

Procedure: Aircrew members had several visual acuity measurements taken before their flight. The measurements were taken with both their own AN/AVS-9 and the WNVG. The aircrew member adjusted his goggles for the distance between his

eyes, and then peered into the ANV-20/20 to adjust his goggles. The aircrew member viewed the resolution chart inside the ANV-20/20. For the AN/AVS-9, he initially focused his objective lenses on the coarse lines in the resolution chart. Then he adjusted his eyepiece by first turning the eyepiece counterclockwise until the image was blurred, then he turned the eyepiece focus clockwise until the image was clear. For that ocular, the aircrew member then returned to the objective lens to "fine tune" the fine lines on the resolution chart. The visual acuities were recorded at simulated quarter moon light level in the ANV-20/20. The aircrew member adjusted his left monocular first while either patching or closing his right eye. The left monocular visual acuity was recorded; this procedure was repeated for the right monocular. Then a binocular visual acuity was recorded. The diopter settings were read off the coarse adjustment ring on the eyepiece lens housing (the aircrew members did not adjust their goggle diopter settings binocularly).

The aircrew member was then handed a pair of WNVGs and he again used the ANV-20/20 to determine his visual acuity with these goggles. The first visual acuity assessment was without snap-on/helper lenses. The aircrew member had to adjust the WNVGs the same as the AN/AVS-9s, except that they had no eyepiece adjustment. Instead the aircrew member had three sets of WNVG visual acuity measurements: baseline (without helper lenses), with -1.0 D helper lenses, and with -1.75 D helper lenses. The aircrew member was allowed to select whatever snap-on lens configuration he wanted for flying. This was recorded as the aircrew member's final flyable configuration. The visual acuity data were recorded from the left outboard, the left inboard, the right inboard, and the right outboard channels. The aircrew member flew with the pair of WNVGs configured with his snap-on lens selection and, upon return from flying, filled out a questionnaire.

Questionnaire: The survey consisted of some brief background questions about the aircrew member, his flying experience level, and NVG flying usage. The purpose of this flight was to determine the utility and level of acceptance of the snap-on lenses.

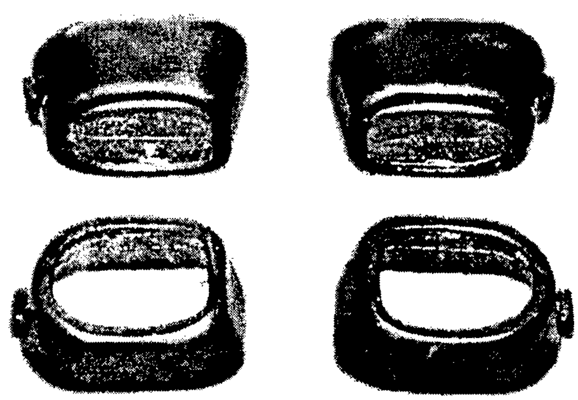

Figure 4: Helper Lenses

3. RESULTS

The baseline diopter measurements of the two WNVG flown in the study are in Table 4. These diopter settings are obtained by taking the average of eight individual measurements using a handheld dioptometer. These prototype WNVGs are intended to have fixed-focus eyepieces at -0.75 D, but they did not turn out that way. The average of the eight measurements for each of the four channels of each pair of goggles is shown Figure 5. Just beneath those values is the average of each channel, which makes up the average diopter setting of the ocular for the goggles. WNVG set number 1 has a diopter settings closer to 0 diopters for each ocular. WNVG set number 2 has a +1.00 D setting for the right ocular, which should be unacceptable for most aviators. It is expected that the aircrew members would be selecting the -1.0 D helper lens at a minimum to bring that eyepiece up to a 0 D, unless they are a hyperope. Since aircrew members tend in the past to prefer more minus diopters, one would expect most aircrew members flying with WNVG set number 2 to select the -1.75 D helper lens.[4] This makes the right ocular -0.72 D. Tables 2 and 3 summarize each WNVG with no helper lens, -1.0 D helper lens, and -1.75 D helper lens.

Table 2: WNVG 1 with no helper lens, -1.0 helper lens, and –1.75 D helper lens

		No Helper Lens		-1.0 Diopters Helper Lens		-1.75 Diopters Helper Lens	
Ocular	**Channel**	**Ocular**	**Channel**	**Ocular**	**Channel**	**Ocular**	**Channel**
Left	**Outboard**	-0.37	-0.31	-1.37	-1.31	-2.12	-2.06
	Inboard		-0.44		-1.44		-2.19
Right	**Inboard**	-0.16	-0.22	-1.16	-1.22	-1.91	-1.97
	Outboard		-0.09		-1.09		-1.84

Table 3: WNVG 2 with no helper lens, -1.0 helper lens, and –1.75 D helper lens

		No Helper Lens		-1.0 Diopters Helper Lens		-1.75 Diopters Helper Lens	
Ocular	**Channel**	**Ocular**	**Channel**	**Ocular**	**Channel**	**Ocular**	**Channel**
Left	**Outboard**	-0.16	-0.23	-1.16	-1.23	-1.91	-1.98
	Inboard		-0.09		-1.09		-1.84
Right	**Inboard**	+1.02	+0.97	+0.02	-0.03	-0.73	-0.78
	Outboard		+1.08		+0.08		-0.67

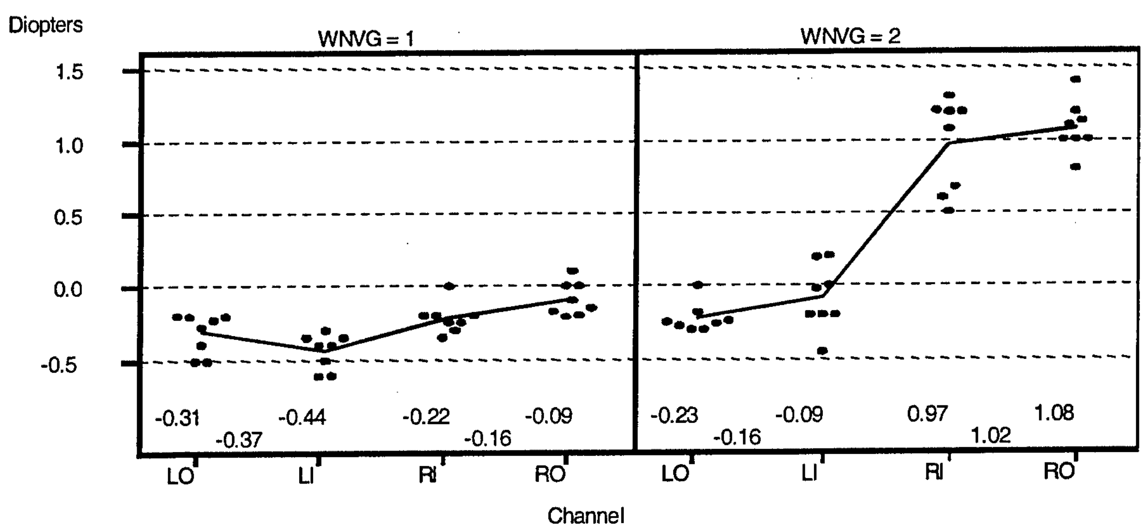

Figure 5: Average WNVG Diopter Measurements for each Ocular. Eight diopter measurements for each channel (LO = left outboard, LI = left inboard, RI = right inboard, RO = right outboard) were recorded. The average of each channel is presented above the average each ocular (values above x-axis).

Table 4 summarizes the data gathered from the aircrew members when they pre-flighted their AN/AVS-9 and the WNVGs. We are presuming that the AN/AVS-9 diopter setting is their ideal setting, and wanted to see how close the aircrew member would get with the three possible combinations of no-helper lens, -1.0 D, or -1.75 D. The diopter settings were read from the pair of AN/AVS-9 using the course adjustment each reading was within +/- 0.25 D. For the difference we subtract the WNVG flyable diopter setting from the AN/AVS-9 setting. For all the aircrew members except for aircrew 8-P on the right ocular, it was possible to achieve a diopter setting within 0.5 D using none or one of the helper lenses. For example, 2-P could have come within -0.38 D from his AN/AVS-9 on the left ocular had he chose the -1.0 D, but he chose the -1.75 D instead. It is interesting to note that only one of the ten aircrew members selected the combination for flying with the WNVG that is closest to his AN/AVS-9 settings and that his visual acuity is the best possible with the clip-on lenses he chose. Unfortunately he ended up not being able to fly the mission, so he was unable to answer our post flight survey.

Table 4: Diopter settings of each aircrew for the AN/AVS-9, and WNVG goggles with snap-on lens. 'Difference' indicates the diopter difference between the AN/AVS-9 and WNVG with the chosen snap-on lens. 'Least Possible Difference' indicates the least difference possible given the following: none, -1.00D, and -1.75D snap-on lens options. If the least possible difference was not chosen, this difference (however small, see 3-AG left) is in bold. Darkened cells indicate those situations when the difference between the AN/AVS-9 and WNVG was greater than 1 diopter.

Ocular	Goggle or Difference	Aircrew using WNVG = 1					Aircrew using WNVG = 2				
		1-P	**2-P**	**3-AG**	**4-FE**	**5-LM**	**6-P**	**7-P**	**8-P**	**9-P**	**10-LM**
Left	AN/AVS-9	-1.00	-0.75	-1.75	-2.00	-2.00	-0.25	0	-2.00	-1.00	-1.00
	WNVG	-0.37	-2.12	-1.37	-2.12	-2.12	-1.16	-0.16	-1.16	-1.16	-1.16
	Difference	-0.63	1.37	-0.38	0.12	0.12	0.91	0.16	-0.84	0.16	0.16
	Least Possible Diff	**0.37**	**-0.38**	**0.37**	0.12	0.12	**-0.09**	0.16	**-0.09**	0.16	0.16
Right	AN/AVS-9	-0.75	-0.75	0	-1.00	-1.75	-1.00	0	-3.50	-1.00	-1.00
	WNVG	-0.16	-1.91	-1.16	-1.91	-1.91	-0.73	0.02	0.02	0.02	0.02
	Difference	-0.59	1.16	1.16	0.91	0.16	-0.27	-0.02	-3.52	-1.02	-1.02
	Least Possible Diff	**0.41**	**0.41**	**0.16**	**0.16**	0.16	-0.27	-0.02	**-2.77**	**-0.27**	**-0.27**

Figure 6 visually illustrates Table 4. The AN/AVS-9 and WNVG data is determined as the actual selected diopter values. The optimal WNVG diopter comes closest to matching their AN/AVS-9 settings. We assume the aircrew member adjusted their AN/AVS-9 to their optimal performance. Additionally, we expect the aircrew member's optimal performance to be at the same diopter value for AN/AVS-9 and WNVG. The questions are: Can the aircrew members using helper lenses achieve a diopter setting close to AN/AVS-9 diopter setting and can they do this selection on their own?

Aircrew member 3-AG selected 0 D for his AN/AVS-9 right ocular. Had he not selected a helper lens, his right ocular for the WNVG would have been -0.16 D. Instead, he chose a -1.0 D helper lens, which gave him a 1.16 D difference between his chosen AN/AVS-9 diopter setting and the diopter setting he flew with. For his left ocular he could have chosen a match that is 0.01 D closer to his ideal AN/AVS-9 setting, but the setting is so close that one could not have argued (based on diopter setting) that his choice is not appropriate.

Aircrew member 6-P similarly could have chosen an optimal left diopter setting had he not chosen to wear a clip-on lens on his left ocular. He does end up selecting the closest possible diopter setting for his right eye by selecting the -1.75 D. Aircrew members 5-LM and 7-P selected what are optimum diopter settings, because the combination of snap-on lenses selected are the closest to their AN/AVS-9 diopter settings.

Aircrew members 8-P, 9-P, and 10-LM selected the -1.0 helper lens for their right ocular. While this demonstrates that none of them are hyperopes, one would have expected that they would have chosen the -1.75 D, based on the fact that two of them had chosen -1.0 D for their AN/AVS-9, and the -1.75 D would have given them -0.73 D. It is possible that the aircrew were influenced by the diopter value labeling on each helper lens. Currently in training, each aircrew member is told that he should select the least minus settings that provides an acceptable visual acuity for their goggles. However, the aircrew member is not briefed in this study on the individual diopter values of each of the channels for their goggles. It is possible that each aircrew member believed they were flying with -1.0 D net setting on their right ocular for WNVG set number 2. Aircrew member 8-P is harder to explain, but as shown in the next table, his visual acuity is not affected.

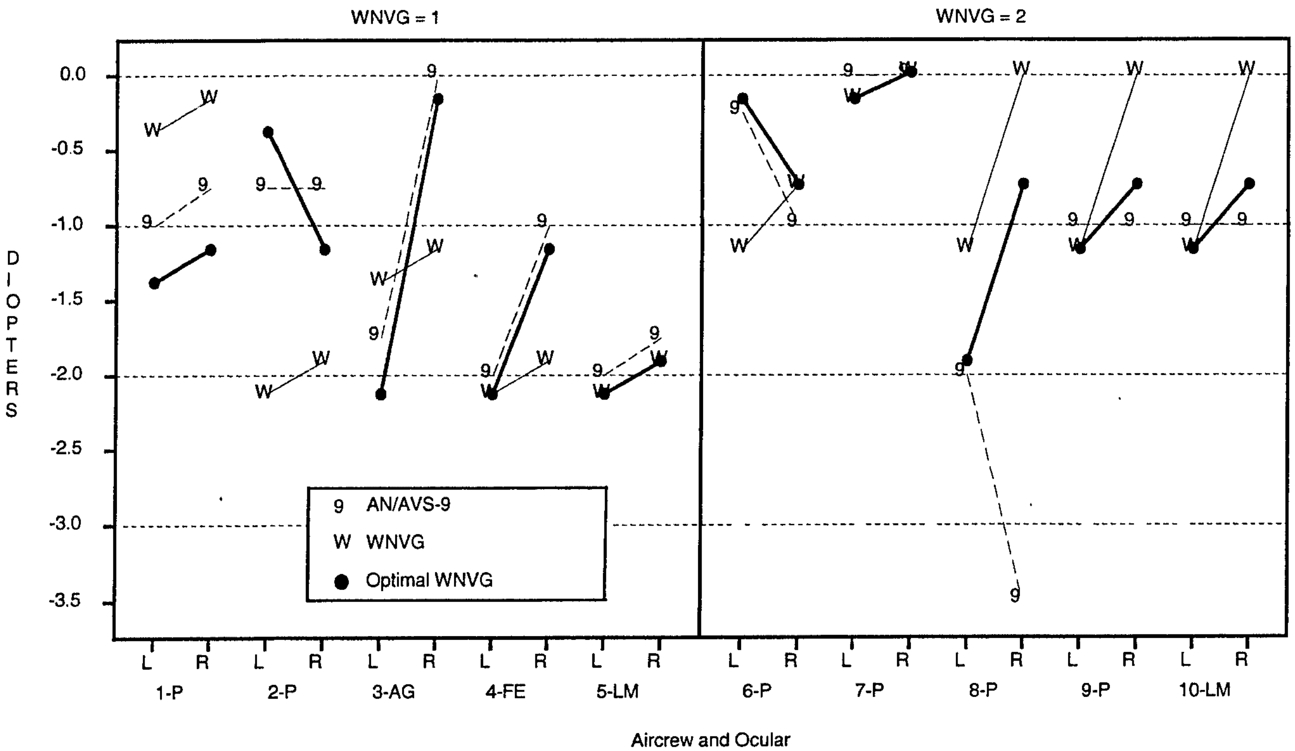

Figure 6: Diopter settings for each aircrew and ocular. The 'Optimal WNVG' setting is that setting, with options of none, -1.00D, and -1.75D snap-on lens, that most closely matches the AN/AVS-9 setting. All aircrew used snap-on lens for both WNVG oculars except 1-P (neither ocular) and 7-P (no snap-on left ocular).

Table 5 shows a summary of results. Each aircrew member tries on a series of lenses combinations: no helper lens, -1.0D, and -1.75 D for each ocular of the WNVG. The aircrew member chose the combination of lenses (or none) that they flew with. One would expect that they would try to attain similar visual acuity (VA) as they have with their AN/AVS-9. One would figure that if he is not able to replicate their AN/AVS-9 diopter setting that he would choose a snap-on lens combination that gives him the best visual acuity. Aircrew members 1-P, 2-P, 4-FE, 5-LM, 8-P, and 10-LM all chose the best possible flyable configuration based on their best VA. Some aircrew members, 3-AG, 6-P, 7-P, and 9-P, chose to fly with configurations that were not based on the best VA. Aircrew member 3-AG should have chosen the -1.75 D snap-on lens versus the -1.0 D for his right ocular because the screening VA indicated that he does have better VA with the -1.75D helper lens. The same could be said for aircrew members 7-P on his left ocular and 9-P on his right ocular.

At the beginning of our questions for the aircrew, we acknowledged that the image quality of the WNVG was not as good as the AN/AVS-9, but that the follow-on WNVG will have equivalent image quality to the AN/AVS-9. It may have been difficult for some aircrew to make an image quality assessment. The aircrew members are left to determine what they consider effective mission accomplishment. Only two aircrew members (1-P and 2-P) did not find WNVG effective, 6-P and 10-LM had answered both yes and no. All four of these people cited an image quality issue or focusing as the reason. From 1-P we would not have expected this result since the final flyable configuration he chose had 20/25 for both eyes with his WNVG, although he was about 0.6 D different with this WNVG from his AN/AVS-9 D for both eyes. Member 1-P did end up switching back to his AN/AVS-9 citing some visual acuity issues and headache, which can be a short-term side effect from wearing NVGs or from eyestrain. So it is possible that the eyestrain from not wearing an eyepiece combination closest to his AN/AVS-9 diopter setting may have been a reason for his headache and decreased visual acuity. This aircrew member did still see the long-term goal of an NVG with an increased FOV as valuable. Aircrew 6-P and 10-LM mentioned a focus problem or a VA problem with the WNVG. Aircrew member 6-P, as discussed previously, could have selected a more helpful set of helper lenses (-1.75 D) for his left ocular, which would have given him better VA. One would have expected aircrew member 10-LM to have a better VA with the -1.75 D snap-on lens since that would have brought him closer to his AN/AVS-9 diopter settings. It is interesting that aircrew member 6-P's right ocular was only 0.27 D different than his -1.0 D AN/AVS-9 setting, yet he was unable to resolve better than 20/60 wearing a -0.73 D right ocular for his WNVG.

Five out of nine aircrew (1-P, 4-FE, 6P, 9-P, and 10-LM) that answered the survey changed from the WNVG back to their AN/AVS-9 during their flying mission. Aircrew member 4-FE actually had improved VA for his left inboard channel and right inboard channel so it was surprising that he switched, but he also mentioned that one of the left oculars would periodically blacken out (an intermittent defect in this particular serial number WNVG). Aircrew members 9-P, 2-P, and 4-FE had issues with the lack of focus adjustment on the outboard objective lenses and other objective focus issues, which they found to be distracting.

Eight of nine aircrew felt that in spite of image issues, which could have been due to the resolution of the WNVG or the inappropriate selection of helper lens combinations, the wider FOV for future pairs of NVGs was worth the loss of adjustment. Aircrew member 2-P probably misunderstood or had forgotten the briefing that he was informed the follow-on WNVG would have all four channels with focusable objective lenses. Aircrew member 10-LM's concern with the wider FOV was that for certain loadmaster maneuvers having a wider FOV could be distracting. Aircrew member 10-LM also stated he could always take a low-tech approach of wearing the lens covers on the outer channel(s). Two aircrew members wore glasses during the flight. One of these two aircrew members wanted the goggles to be brought closer to his face, the other felt the goggles sat too close to his face. Since each aircrew member wears their glasses at different positions on their noses, they have a requirement for varying fore/aft adjustment.

Table 5: Visual acuity (Snellen denominator: 20/xx) of initial testing and final flight configuration for each channel (Unf = unfocusable), along with choice of snap-on lens and responses to primary questions. Bolded cells (ocular) indicate the goggle setup closest in diopter setting to the AN/AVS-9. Darkened cells indicate selection of a snap-on lens that did not have the best acuity for the initial tests.

Goggle	Goggle Setup	Channel	Aircrew using WNVG = 1					Aircrew using WNVG = 2				
			1-P	**2-P**	**3-AG**	**4-FE**	**5-LM**	**6-P**	**7-P**	**8-P**	**9-P**	**10-LM**
AN/AVS-9	Goggle Only	Left	20	25	25	30	25	25	25	20	30	20
		Right	20	25	30	30	25	25	25	25	25	20
WNVG	Goggle Only	LO	35	**Unf**	40	60	Unf	**Unf**	**60**	30	Unf	40
		LI	25	**Unf**	35	40	30	**Unf**	**30**	25	Unf	35
		RI	25	25	**35**	30	30	Unf	70	25	Unf	Unf
		RO	40	Unf	**70**	60	35	Unf	Unf	35	Unf	Unf
	Goggle with -1.00D Snap-on	LO	**60**	50	60	60	Unf	Unf	40	25	**35**	**50**
		LI	**30**	35	30	35	30	25	25	20	**20**	**30**
		RI	**25**	**30**	35	**30**	30	Unf	**35**	20	60	40
		RO	**50**	**50**	Unf	**60**	35	Unf	**70**	25	45	Unf
	Goggle with -1.75D Snap-on	LO	70	45	**70**	**50**	**Unf**	35	45	**30**	25	40
		LI	45	25	**35**	**25**	**25**	25	25	**25**	25	35
		RI	30	25	30	30	**25**	**70**	40	**30**	**50**	**40**
		RO	45	45	60	60	**25**	**70**	50	**35**	**30**	**Unf**
	Final Flight Config	LO	35	45	50	50	Unf	60	40	25	30	50
		LI	25	25	30	25	25	25	25	20	25	30
		RI	25	25	30	30	25	60	35	20	40	40
		RO	40	45	50	60	25	60	50	25	30	Unf
	Left Flight Lens		none	-1.75	-1.00	-1.75	-1.75	-1.00	none	-1.00	-1.00	-1.00
	Right Flight Lens		none	-1.75	-1.00	-1.75	-1.75	-1.75	-1.00	-1.00	-1.00	-1.00
Q1. Was WNVG effective for mission accomplishment?			N	N	Y	Y		Y&N	Y	Y	Y	Y&N
Q2. Was WNVG bothersome so switched back to AN/AVS-9?			Y	N	N	Y		Y	N	N	Y	Y
Q3. Discounting image quality, was increased FOV worth the loss of adjustment?			Y	N	Y	Y		Y	Y	Y	Y	Y&N

CONCLUSION

Aircrew members gave a favorable response to the use of snap-on/helper lenses. This is important because aircrew members are willing to forgo having continuously adjustable eyepieces, if they can have an increased FOV. Like the surveys conducted in 1992 and 1993, these results support the findings that FOV and resolution are a much-desired combination to increase war fighter capability.[2] We were further able to objectively demonstrate that we could have an acceptable range of diopter settings had we let the investigator or technical assistant select appropriate diopter settings for the aircrew members. The limited diopter settings did not seem to impact VA. There is comparable VA between the WNVG and AN/AVS-9. Aircrew member 8-P is the only aircrew member that we could not get within 0.5 D of his AN/AVS-9 setting. Aircrew member 8-P demonstrated the ability to accommodate a wide range of diopter values and had an impressive ability to resolve with excellent visual acuity a wide range of diopter choices. This helps illustrate how individual humans can vary in their visual abilities. One would not have anticipated such a wide range for this individual since he is one of the oldest aircrew at 41 years of age.

Another item of interest is the variance of visual acuity for the same pair of WNVG in any given situation from no-helper lenses or the different helper lenses from one aircrew member to the next. A future study is needed to examine the differences in aircrew member determination of their own VA. The current methods of accessing NVG resolution involves using humans, which is inherently not objective.[5] Each aircrew member subjectively makes a decision on the setting that provides them with the best resolution.

Some aircrew members who repeated their visual acuity measurements for their final flyable configuration had a different VA than with their first measurement. It is possible that they had time for their eyes to accommodate. If the eyes are accommodating to an inappropriate self-selected diopter setting, this may contribute to an earlier onset of eye fatigue and headache.[4]

If the follow-on WNVG has a fixed-focus eyepiece of -1.0 D, utilizing snap-on/helper-lenses is viable in providing a wider range of diopter settings for the aircrew members. Based on this limited study, it appears that snap-on lenses will help a follow-on WNVG. If there is an individual that cannot tolerate a discrete number of helper-lenses, then we can specially fit those individuals. Further study to determine the appropriate number of helper lenses needs to be developed. This will optimize aircrew member VA and reduce the chance for eye fatigue.

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Brief Biographies

Share-Dawn P. Angel was commissioned into the US Air Force in 1993. She is currently assigned to the Air Force Research Laboratory, Human Effectiveness Directorate, Crew System Interface Division, Visual Display Systems Branch, where her current position is Chief of Aerospace Vision Research. Before coming to the Air Force Research Laboratory at Wright-Patterson AFB OH, she was a flight surgeon attached to the 9th Special Operations Squadron (Night Wings), Eglin AFB FL. She has over 60 hours of NVG time flying in MC-130P Combat Shadows. In 1993 she received her BS degree in Biology from George Mason University, Fairfax VA, and she is a graduate of AFROTC from College Park, University of Maryland. She earned her medical degree from the Uniformed Services University, Bethesda MD in 1997.

Doug Franck has been employed by the US Air Force since 1988. He is currently assigned to the Air Force Research Laboratory, Human Effectiveness Directorate, Crew System Interface Division, Visual Display Systems Branch, where his current position is deputy program manager for the Helmet Mounted System Technologies program the past four years. He has BS degree in Electrical Engineering and a MS degree in Industrial Engineering.

Aircrew visual acuity viewing with different night vision goggle eyepiece diopter settings

Share-Dawn P. Angel*, J. Bruce Baldwin
Air Force Research Laboratory, Battlespace Visualization Branch
2255 H Street, Wright-Patterson AFB OH 45433-7022

ABSTRACT

The AN/AVS-9 night vision goggle (NVG) has an eyepiece lens that can be adjusted from +2 to -6 diopters (D). We have shown previously[1,2,3] that on average NVG users tend to select about -1D, with a range of +0.5D to -4D[3]. This study was designed to evaluate NVG visual acuity (NVG VA) and subjective ratings for a range of diopter settings including user-selected and three fixed settings of -0.25D, -1D and -2D. Twenty-one experienced USAF Special Operations aircrew members, including 15 pilots, served as subjects. The median user-selected setting was -1.25D and ranged from +0.5D to -3.5D. Only 2 of the 21 subjects had user-selected NVG VA significantly better than a fixed setting of -1D. Of those two, one was not wearing prescribed glasses and the other was 49 years old, presbyopic, and could not focus through the -1D lenses. Subjective ratings and NVG VA indicated that most people could fly with a fixed setting of -1D for each eye, although two individuals needed different diopter settings for the right and left eyes. The new Panoramic NVG (PNVG) has a fixed eyepiece focus of -1D. Results suggest the PNVG should have a limited set of accessory lenses available.

Keywords: Aircrew, ANV-20/20, AN/AVS-9, autorefractor, diopter, field-of-view, F4949, Landolt C, night vision goggle, NVG, Panoramic night vision goggle, PNVG, visual acuity

1. INTRODUCTION

The most common night vision goggle (NVG) used by US Air Force aircrew members is the 40-degree field-of-view AN/AVS-9, commonly called the F4949. It has two separate image intensifier tubes, each with a user-focusable objective lens assembly, and an eyepiece assembly with a user-focusable range from +2 to -6 diopters. We have shown[1,2,3] that there is a rather wide range of focus settings selected by users of the AN/AVS-9, where some aircrew inexplicably self-select eyepiece settings greater than -3 diopters. A new 95-degree field-of-view Panoramic NVG (PNVG) is being transitioned into the US Air Force and Army. The PNVG has four intensifier tubes, and four separate objective lens assemblies. The four eyepiece lenses are fused into two assemblies (Figure 1). Due to engineering constraints the PNVG has a fixed eyepiece focus, chosen to be -1 diopter. Although studies suggest that most users will be able to see well with -1 diopter eyepieces [1,2,3,4,5], the PNVG will be shipped with a set of accessory snap-on lenses for users who require an eyepiece focus of more or less than -1 diopter. This study was designed to evaluate the effect of AN/AVS-9 eyepiece focus on NVG VA using an objective and repeatable acuity task. NVG VA was acquired with a computerized display for a range of eyepiece diopter settings that included three fixed settings (-0.25D, -1D and -2D), and three user-selected settings (S1, S2, and S3) that were determined by each subject prior to NVG acuity testing. The subject was not aware at any time which setting he was tested with, or even if he was ever tested with his own settings. In addition to NVG visual acuities, each subject rated the visual acuity and comfort of each setting. The goal of the study was to determine, based on NVG VA and subjective ratings, how many aircrew would likely be able to fly safely and comfortably with the standard -1 diopter setting in the PNVG.

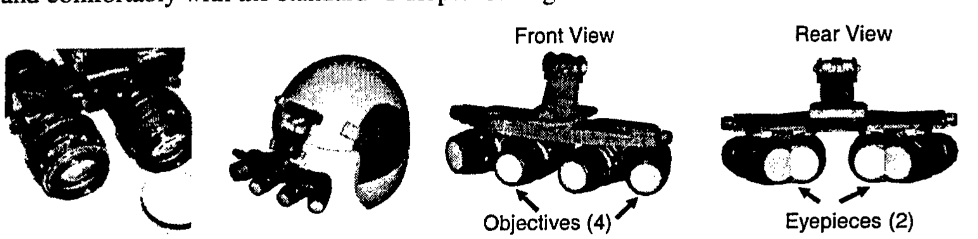


Figure 1. AN/AVS-9 NVG showing Teflon ring used to mask the eyepiece setting, and a drawing of the PNVG.

*Share.Angel@wpafb.af.mil; http://www.hec.afrl.af.mil; telephone: (937) 255-9247; fax (937) 255-8366

2. METHODOLOGY

2.1 Subjects

Twenty-one male US Air Force Special Operations aircrew members participated in the study. Their ages ranged from 23 to 53 years with a median of 38. The NVG flying experience ranged from 51 to 4000 hours with a median of 500 hours. Aircrew included 15 pilots, 5 loadmasters, and 1 flight engineer. Demographic information collected included: date, squadron, age, gender, aircraft, total flying hours, NVG flying hours, and history of contact lens or glasses wear. Data collected included: glasses prescription, autorefractor prescription, aircrew member user-selected NVG diopter settings, and binocular visual acuity with and without NVGs. Prior to testing, each subject received an informed consent briefing and signed an Informed Consent Document.

2.2 Equipment

2.2.1 NVG. The aircrew used a single AN/AVS-9G NVG (ITT, Roanoke, VA) calibrated by our lab (AFRL) to be within +/- 0.25 D of the displayed diopter setting. All subjects viewed the visual acuity targets with the NVG mounted on their personal helmet using a standard NVG mount.

The value of the eyepiece setting was masked to the subjects with a thin Teflon ring that covered the diopter scale but allowed full range-of-motion of the eyepiece lens. The Teflon ring could be easily moved so the experimenter could read and set the diopter value (Figure 1).

2.2.2 Computerized Visual Acuity. Visual acuities, with and without the NVG, were objectively acquired using a Macintosh G4 with Apple 23 inch Cinema HD display (Figure 2.). Visual acuity software was the Freiburg Visual Acuity & Contrast Test (FrACT). This shareware written by Dr. Michael Bach[6] is available at http://www.ukl.uni-freiburg.de/aug/mit/bach/index.html. The test presents a standardized Landolt C with an 8 alternative forced choice task. The test always starts by presenting a letter C at a gap visual angle of 10 minutes of arc equivalent to 20/200 in Snellen notation. As the subject makes correct responses the size of the C becomes smaller and quickly approaches threshold. The size of the C is adjusted up or down based on the subject's responses and a final visual acuity is calculated for a letter size that would be seen 56.25% of the time. Visual acuities are calculated by the computer using a Best PEST (Parameter Estimation by Sequential Testing) algorithm[7]. After each threshold visual acuity the software displays the acuity on the monitor and also stores the information in the clipboard. For this experiment, the displayed acuity was manually recorded and the clipboard was also copied to an Excel© spreadsheet for later analysis.

The Apple Cinema HD monitor was used at a brightness setting that provided a luminance of 27 fL without any filters in place. The display was made NVG compatible by filtering with a Nightshield Full Color LCD Class B filter (Korry Electronics Co., Seattle, WA), and an additional neutral density filter (Lee Filters USA, Burbank, CA). The display was viewed through a circular aperture that subtended 1.8 degrees of visual angle at a 6 meter (20 feet) viewing distance. The aperture was centered on a white foam board, 7.3 X 9.6 degree background. The available filters and display luminance were chosen to approximate "quarter moon" illumination of the NVG VA task. Measured

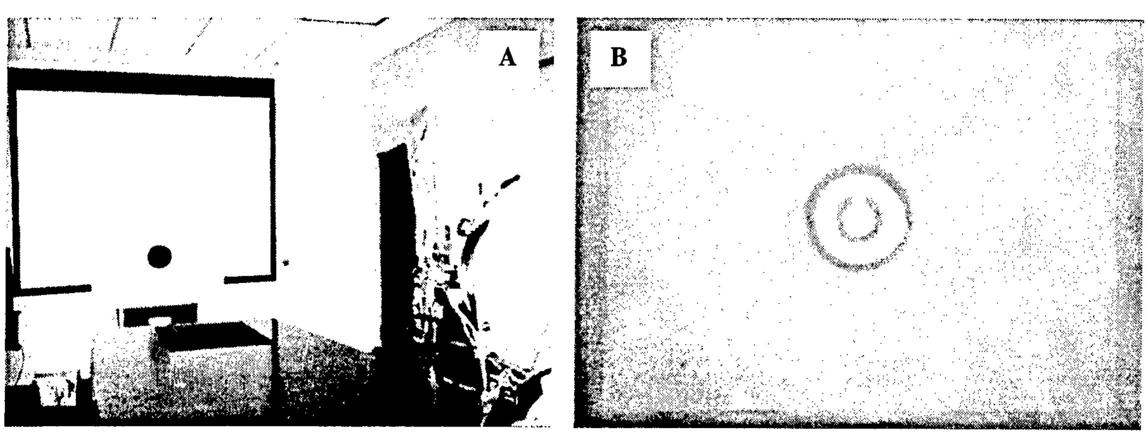


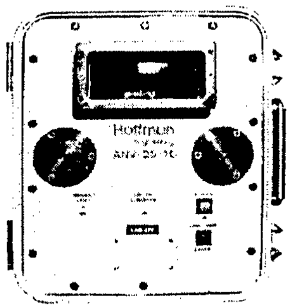
Figure 2. Computerized visual acuity setup (A) with example of image seen through NVG (B).

NVIS radiance of the display (Photo Research, PR 1530) was 1.58 X 10^{-9} watts/cm^2 - str through the aperture and 1.23 X 10^{-9} watts/cm^2 - str for the background. Background illumination was provided by a custom made halogen light source arranged off axis at 3 meters from the display. This circular background illumination extended beyond the 7.3 X 9.6 degree foam board and filled approximately one third of the 40-degree field-of-view of the NVG. The configuration and radiance of the background varied some with change in testing location. The contrast of the Landolt C as seen without the NVG was measured at 99%, and through the NVG was 50%. The lower contrast seen with the NVG resulted from the interaction of the filters with the visible and near infrared transmission of the dark and light portions of the computer display.

2.2.3 Autorefractor and auto lensometer. Although complete eye exams were not completed on the subjects, refraction data was obtained from 20 of the 21 subjects using a Nikon Retinomax K-plus autorefractor (Nikon Instruments, Inc). The autorefractor objectively measures and displays an individual's refractive error (spectacle Rx) by analyzing an infrared image passed through the eye's optics after being reflected from the back of the eye. We measured the prescription from currently used glasses from four subjects using a Marco LM-820 auto lensometer (Marco Inc., Jacksonville FL).

2.3 Procedure

2.3.1 Aircrew-selected eyepiece settings. Prior to visual acuity testing, each subject "pre-flighted" the NVG, as he would prior to flying, using a Hoffman ANV-20/20 (Figure 3) to focus the objective and eyepiece lenses. The diopter setting for each eyepiece was recorded and the subject refocused two additional times, with the three user-selected readings recorded as S1, S2 and S3. Subjects also reported visual acuity while looking at the ANV-20/20 acuity targets through the user-selected diopter setting. The user-selected eyepiece diopter settings were later used to measure NVG VA at those settings.



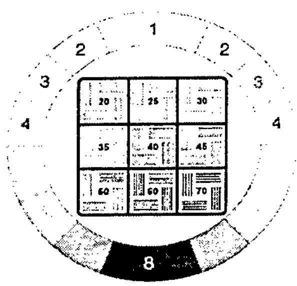


Figure 3. Hoffman 20/20 unit.

2.3.2 Measurement of refractive error and spectacle prescription (Rx). After recording the user-selected eyepiece settings, 20 of the 21 subjects had their refractive error measured with a Nikon Retinomax K-plus autorefractor (Figure 4). The autorefractor objectively measures myopia, hyperopia, and astigmatism. In lieu of a full eye exam with refraction, the autorefractor can estimate an individual's refractive error in a few seconds. Although there is variability when measuring some individuals, an autorefractor measurement is reasonably reliable and repeatable[8]. Four subjects had their glasses available and the prescription was determined with a Marco LM-820 autolensometer. Two other subjects had a written copy of a recent spectacle prescription for comparison with the autorefractor results. There was reasonably good agreement between the autorefraction and spectacle Rx for twelve eyes of six subjects with a known spectacle Rx (Figure 4). This suggests that the autorefractor results on individuals not wearing glasses were good estimates of any uncorrected refractive error such as myopia. Autorefraction data was used to calculate "net" NVG eyepiece settings, as in section 2.3.5.

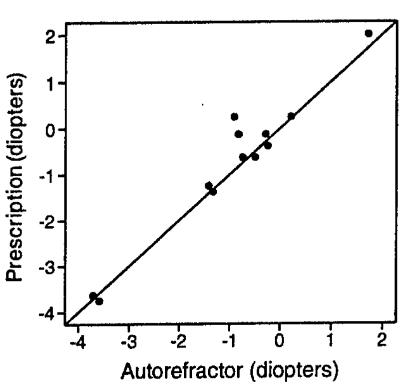


Figure 4. Known spectacle Rx vs measured autorefractor Rx.

2.3.3 Measuring visual acuity with and without NVG. Subjects were comfortably seated facing the computer monitor and instructed on how to take the computerized visual acuity test. Tests distances varied between 12.5 and 22.3 feet over the four test locations, but the display was calibrated for each test distance. As described above, a letter "C" was displayed on the monitor after the subject initiated a trial. The subject selected a number on a numeric keypad that corresponded to one of the eight directions of the gap in the C (Figure 2). After 24 presentations the computer-

calculated visual acuity was recorded and the subject initiated the next trial. After at least three practice trials, each subject's visual acuity was measured and recorded three times in normal room light without NVG.

With room lights off and NVG compatible filters in place, subject focused the NVG objective and eyepiece lenses to optimize NVG VA for viewing the letter C on the display. Subjects viewed through the NVG in their habitual flying condition, i.e., with or without glasses or contact lenses. Subjects completed at least two more practice trials with the NVG, or until they were comfortable with the procedure.

Each subject then recorded one NVG VA run (3 trials/run) with each of the user-selected eyepiece diopter settings (S1, S2, and S3), and three NVG VA runs for each fixed setting of -0.25D, -1D and -2D for a total of twelve runs (36 total trials/subject). The order of diopter settings tested was pseudo randomized and counter-balanced across subjects. The objective lens focus remained where the subject had focused it for the distance of the computer display. One of the authors, SDA, changed the eyepiece diopter setting after each run without the subject's knowledge of the setting. All visual acuities, with and without NVG, were obtained in one session which lasted about one hour.

2.3.4 Subjective ratings questionnaire. After acquiring three consecutive NVG visual acuities at a particular diopter setting, subjects were asked to compare the visual acuity and comfort of that eyepiece diopter setting with their best recollection of the NVG with which they normally fly during actual training and operations. Subjects were asked to rate the setting with respect to 1) Clarity of vision, 2) Comfort of the setting, and 3) The setting's tendency to create nausea. The rating scale was: 1 = much better, 2 = somewhat better, 3 = same, 4 = somewhat worse, and 5 = much worse than their personal setting with their NVG. The ratings were acquired for each of the twelve NVG acuity runs.

2.3.5 Calculation of net eyepiece setting, or accommodative demand. Uncorrected refractive error, such as needing glasses but not wearing them, causes the eyepiece diopter setting shown on the NVG to be different than what is actually viewed by the subject. For example, if an individual needed glasses with prescription -1D but was not wearing glasses, and selected -2D in the eyepiece setting, the net diopter setting would be -1D. That is, 1 of the two diopters would compensate for the uncorrected refractive error. To examine the effect of uncorrected refractive error we calculated a net eyepiece setting, or accommodative demand:

Net = glasses Rx – autorefractor Rx + NVG diopter reading. For individuals not wearing glasses the first term becomes 0. These corrected diopter settings explain the performance of some subjects as described in the results section.

3. RESULTS/ANALYSIS

3.1 Quality control

3.1.1 Repeatability limits. Threshold visual acuity measurements are known to be repeatable only to within one to two lines on an eye chart[9], or the equivalent of one to two lines on a computerized visual acuity test[10]. Repeatability limits for NVG VA has also been shown to be about one to two lines[11,12]. Estimates of repeatability for the visual acuity FrACT test were obtained in two ways. Each day, author JBB, who had experience testing with the FrACT, took ten consecutive threshold visual acuities with and without NVG, at each of the four test locations, for six consecutive days. Repeatability limits were calculated for JBB and for subjects tested with the same NVG eyepiece diopter setting. Repeatability limit (rL) is defined as: approximately 95% of all pairs of trials, from the same aircrew number and run, should differ in absolute value by less than the rL. For aircrew the variance estimate used for rL is the pooled variance of the three trials from each aircrew number and run. Some settings from particular aircrew were not used when the visual acuity values were far worse for those settings compared with other settings from the same aircrew number: -0.25D for #14, and -2D for #2, #6, and #10. All rLs are between the equivalent of 1.3 to 2 lines on an eye chart. Although the FrACT is quite variable, the repeatability limits are typical.

Repeatability limits were also calculated for the subjects' ability to select the eyepiece diopter setting for the three user-selected settings: S1, S2, and S3. The median absolute difference between S1, S2, and S3 was 0.25D and the rL was 1.17D. For the difference between right and left eyes, the median absolute difference was 0.50D and the rL was 1.39D. This indicates, in part, a lack of precision for an individual to repeatedly select an eyepiece diopter setting while using the Hoffman 20/20 unit using current practice.

Table. Repeatability limits of visual acuity with and without NVG

Variable	Subjects	Wearing NVG	rL	Mean	rL % of Mean
Snellen(20/xx)	JBB	No	3.8	9.1	42
		Yes	8.2	27.7	29
	Aircrew	No	3.8	11.4	34
		Yes	12.6	34.6	36
Log MAR	JBB	No	0.19	-0.35	
		Yes	0.13	0.14	
	Aircrew	No	0.16	-0.23	
		Yes	0.16	0.23	

3.1.2 Location and order effects. Because the four test locations had different conditions, such as test distance, we looked for an effect of location on visual acuity. The Snellen visual acuities from author JBB were used as the dependent variable in a one-way analysis of variance with location as the factor. There was not a significant difference among the last three of four locations when wearing NVG (p=0.07) with means: loc 2 = 20/28.4, loc 3 = 20/27.9, loc 4 = 20/25.4 (JBB acuities were not collected at the first location which only had one subject). Nor was there a significant difference among the three locations without NVG (p=0.38) with means: loc 2 = 20/9.4, loc 3 = 20/8.9, loc 4 = 20/ 9.0.

Because NVG acuity testing took about an hour to complete, we looked for an effect on subjects from fatigue, learning, etc., by performing a repeated measures analysis of variance on the order of presentation of the twelve NVG VA runs. For the three -1D settings, which were spaced over the twelve runs, there was not a significant difference in run order (p=0.36), with means: order 1 = 20/32.7, order 2 = 20/31.7, and order 3 = 20/32.8.

3.1.3. Missing data and outliers. Each of the 21 aircrew performed 12 runs of 3 trials per run. Of the 756 total trials, 32 were not properly recorded and saved to the computer database and 10 were considered outliers for being clearly different from other trials from the same aircrew and diopter setting and for being inconsistent with other values from the same aircrew in general. These outliers were removed from the data base for further analysis and are not included in the figures below.

3.2 NVG VA with user-selected and fixed -1D settings

Figure 5 shows composite NVG VA scores for all 21 subjects while viewing through their user-selected diopter settings (average of S1, S2, S3) and a fixed setting of -1D. The data are sorted by subject with respect to the mean difference between the user-selected and -1D NVG VA. Subjects to the left have better user-selected acuity and those to the right have better acuity with the fixed -1D eyepiece. Each data point is an average of nine NVG visual acuities acquired over three runs, with the exception of individuals with outliers or missing data. Significance was based on a 2-tailed 2-sample

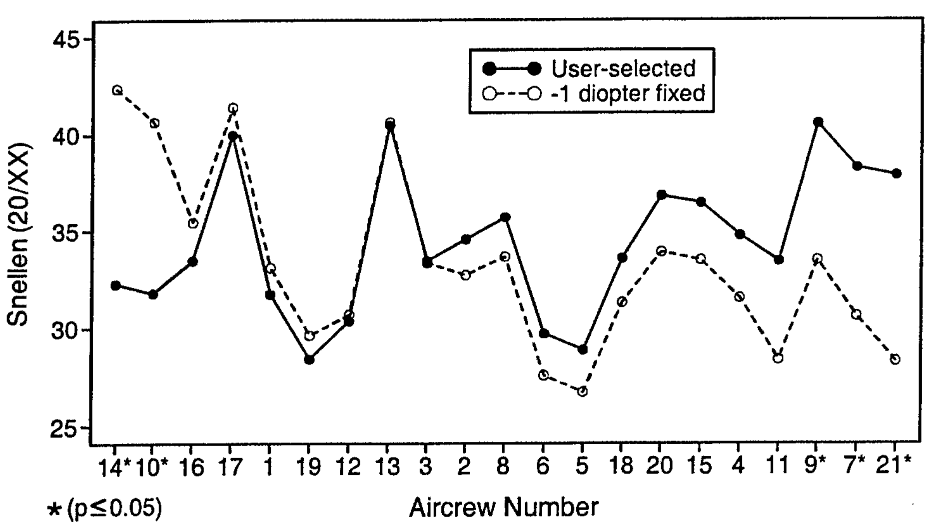


Figure 5. Average NVG VA with user-selected and -1D eyepiece settings. Each data point is the average of nine acuities acquired over three runs. The data are sorted by subject with respect to the mean difference between the user-selected and -1D settings. Subjects to the left have better NVG acuity with their user-selected setting and those to the right have better acuity with the fixed -1D eyepiece.

t-test. Figure 5 indicates that 19 of the 21 subjects could see as well with the fixed -1D eyepiece as they could with their user-selected settings. Results from each individual will be detailed below. Briefly, aircrew number 14 had glasses

prescribed but did not wear them for flying nor for the NVG acuity test. His user-selected settings were about -2.25D, and had he been wearing his glasses we calculate (as described below) that he would have selected about a -1D. Aircrew number 10 was a presbyopic pilot, age 49, with user-selected settings of close to 0 diopters. Apparently he was unable to accommodate (focus) through any negative power lenses. Aircrew numbers 10 and 19 were the only subjects whose subjective ratings indicated the fixed -1D setting was worse than their user-selected setting. Subjective ratings from aircrew numbers 8, 9, 13, and 20 indicated the fixed -1D was better than their user-selected setting. Rating results are found in section 3.3.

3.3 Subjective ratings

Subjects rated each of their twelve runs (9 fixed, 3 user-selected) with respect to 1) Clarity of vision, 2) Comfort of the setting, and 3) The setting's tendency to create nausea. The rating scale was: 1 = much better, 2 = somewhat better, 3 = same, 4 = somewhat worse, and 5 = much worse than their personal setting with their NVG. Ninety-six percent of nausea ratings were 3; therefore, nausea was not used in any analysis. For visual clarity and comfort, the mean rating was determined for each subject for user-selected and -1D fixed settings. Using a 2-tailed paired t-test, there were no significant differences ($p > 0.14$). Rating visual clarity, the mean user-selected and -1D ratings were 3.48 and 3.35, respectively. Rating comfort of the setting, the mean user-selected and -1D ratings were 3.51 and 3.32. Ratings for all twelve runs are found at the top of each individual's graph in Figure 6.

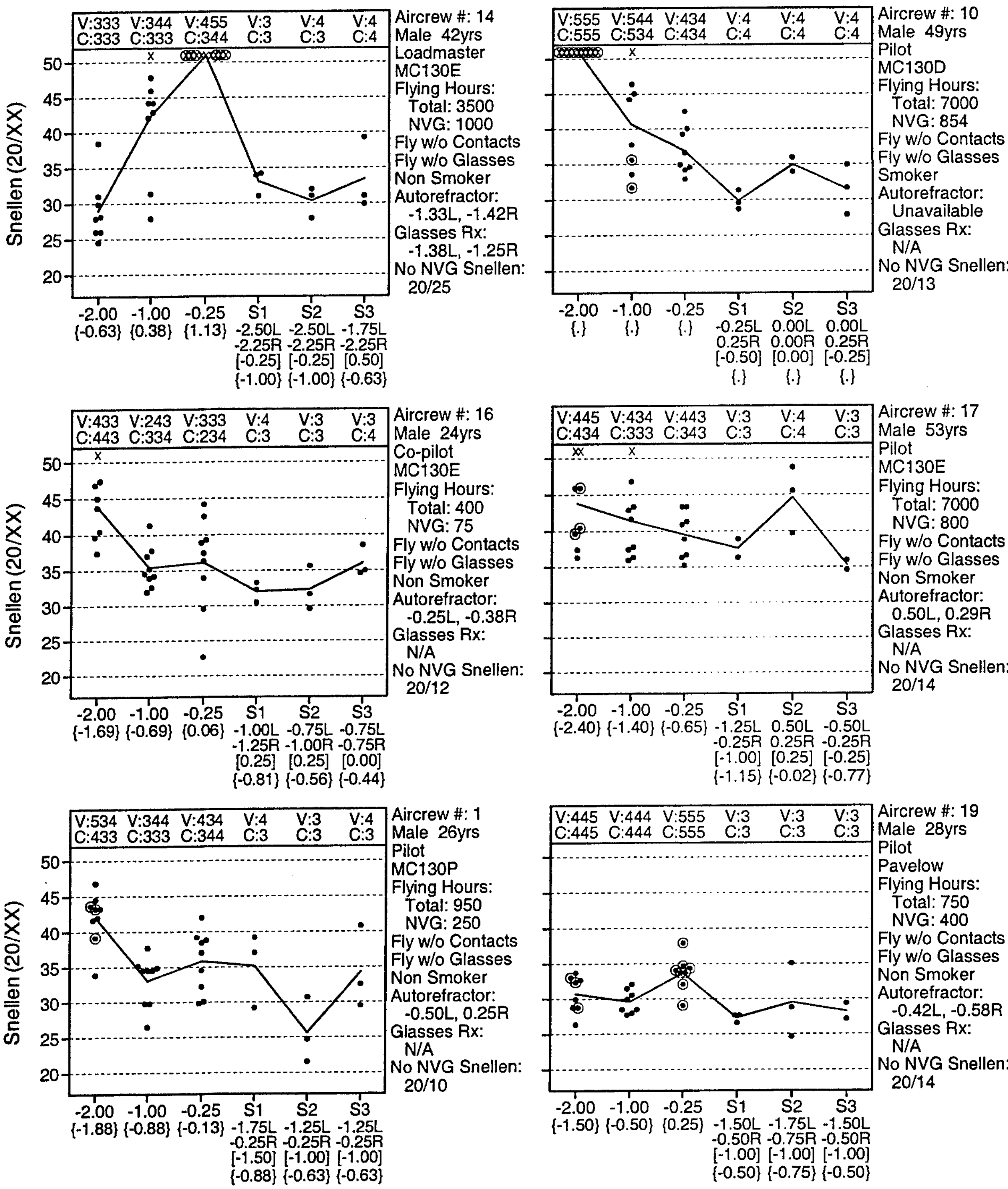
3.4 Individual results

Figure 6 contains detailed results from each of the 21 aircrew members. Each individual's graph shows the Snellen NVG VA for each of the six diopter settings used including the three user-selected (S1, S2, S3) and the three fixed (-0.25D, -1D, -2D) settings. All NVG visual acuities are plotted as Snellen visual acuity (20/xx). A bold line tracks the mean acuity at each diopter setting. The subjects are sorted as in Figure 5 with individuals who saw significantly better with their user-selected setting first and those who saw better with the -1.0 D fixed setting last. Results from some individual subjects merit detailed analysis and are presented below.

3.4.1 Aircrew number 14. The data seem to show that this loadmaster saw well with his user-selected setting of about -2.25D, which is a diopter more minus than the average for all users. NVG acuity at -1D, and especially -0.25D, was poor, and the subjective ratings at -0.25D were poor. This individual had spectacles but stated he never wore them for flying, but instead dialed in whatever diopter setting on his AN/AVS-9 that gave good NVG VA. We calculated the net diopter setting, or accommodative demand (see section 2.3.4) for his user-selected settings to be -1D. The -2D fixed setting (net -0.63D) showed NVG acuity as good as his user-selected settings. If he were to wear glasses while flying, as required by regulation, we predict he would see well and be comfortable with a -1D.

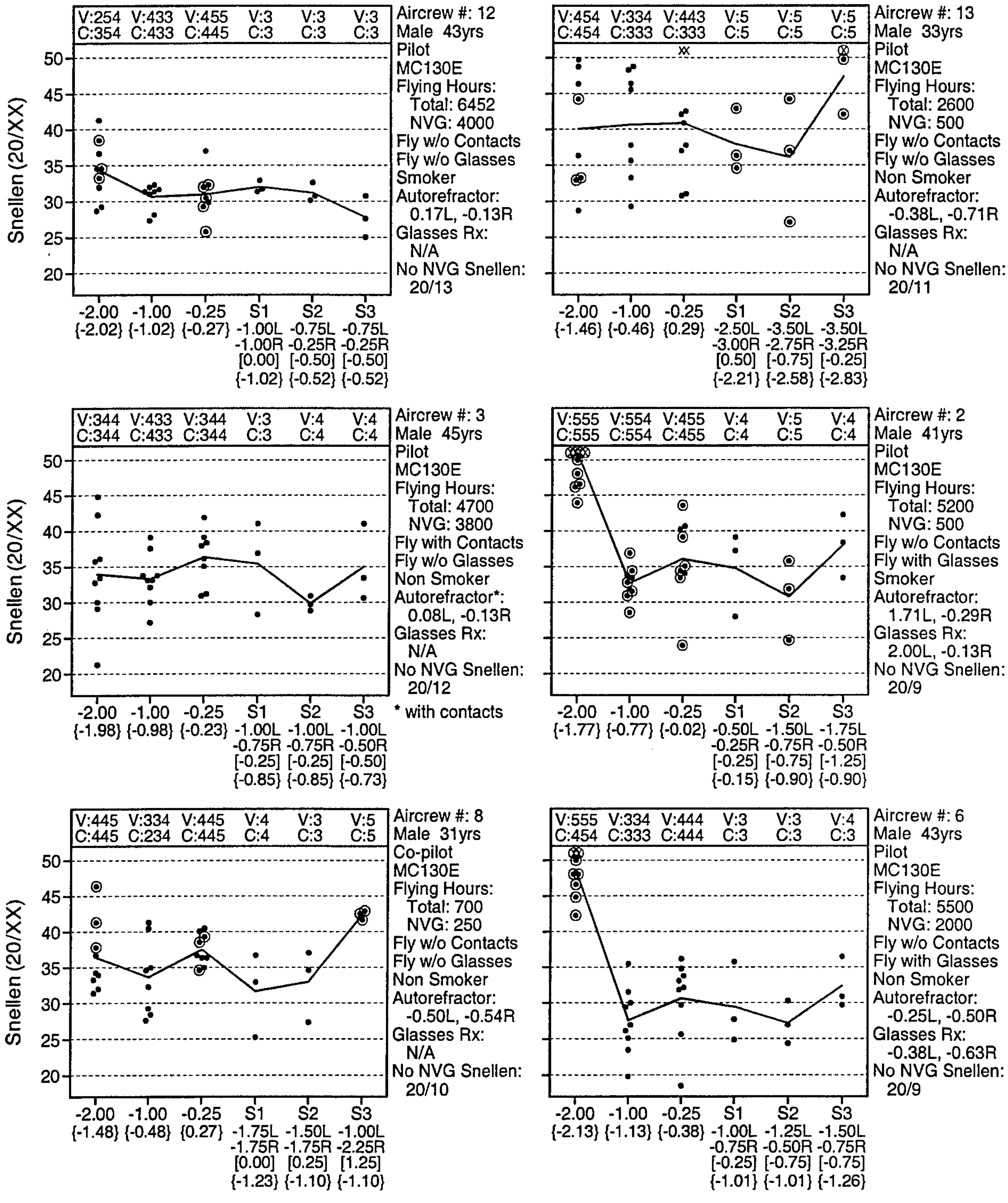
3.4.2 Aircrew number 10. This pilot was the only other subject who saw better with his user-selected settings than the fixed -1D. He is an older presbyopic individual, who user-selected settings close to 0 diopters, and had trouble focusing with any of the negative power settings. We were unable to obtain an autorefractor Rx because of very small pupils. Because he selected 0 power lenses, when most people select low minus lenses, we predict an eye exam would reveal a low plus spectacle prescription, which is consistent with the inability of an older presbyopic individual to focus with negative power lenses. If this individual were to fly with the PNVG he would probably not see well with the fixed -1D eyepiece and would need an accessory snap-on lens.

3.4.3 Aircrew number 1. This young pilot did not wear glasses to fly but had an autorefraction Rx that was a little nearsighted in the left eye (-0.50D) and a little farsighted in the right (+0.25D). That Rx is consistent with being able to see at least 20/20 in each eye on a flight physical eye exam, but there is a difference between the eyes of ¾ of a diopter when viewing with both eyes open. Consistent with this difference, his user-selected eyepiece differed by about one diopter apart, and his comments and subjective ratings indicated he was not comfortable with the -0.25D or -2D settings, and that either the left or right eye was blurry. With the fixed -1D setting the blur in either eye was minimized and his NVG acuity and comfort ratings were good. Even though his NVG VA would likely be good with a fixed -1D eyepiece in the PNVG, he would probably benefit from accessory snap-on lenses with different powers for the left and right eyes.



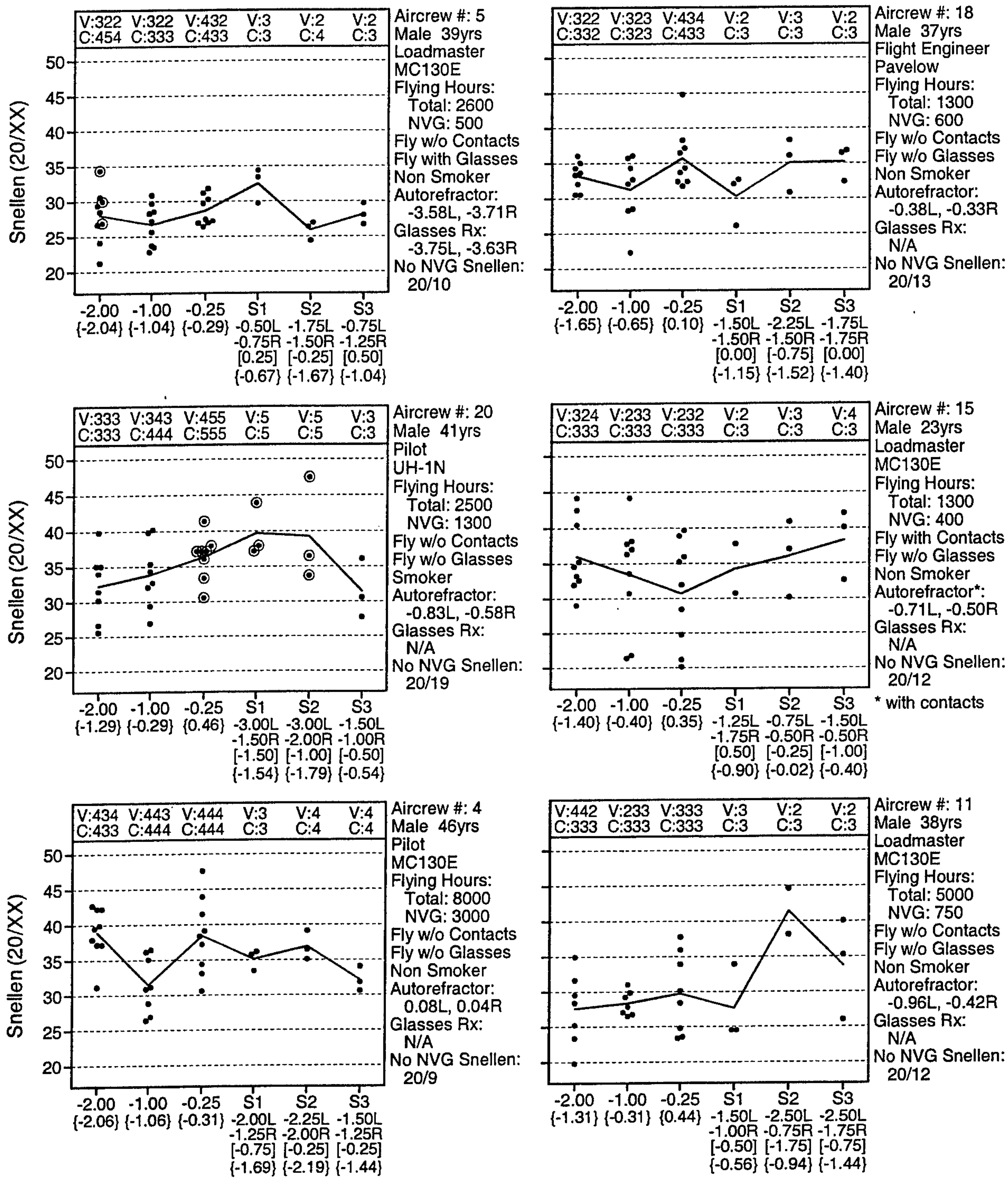
X = greater than 50 O = much worse than personal [ ] = left - right eyepiece { } = accommodative demand

Figure 6. Individual results. On the right side of each individual graph are demographic data, autorefraction and spectacle Rx when available, and visual acuity without NVG. Above are subjective ratings where V is visual focus clarity and C is comfort. Any rating of 5 (much worse than personal flying eyepiece setting) has the data point circled. Data points are all NVG visual acuities in Snellen notation for the three user-selected eyepiece settings (S1, S2, S3) and the three fixed settings. Below the eyepiece diopter settings are the difference in left and right settings [ ] and the calculated "net" setting, or accommodative demand, based on autorefraction data { }. The bold line tracks the mean NVG VA for each setting. Subjects sorted as Figure 5.



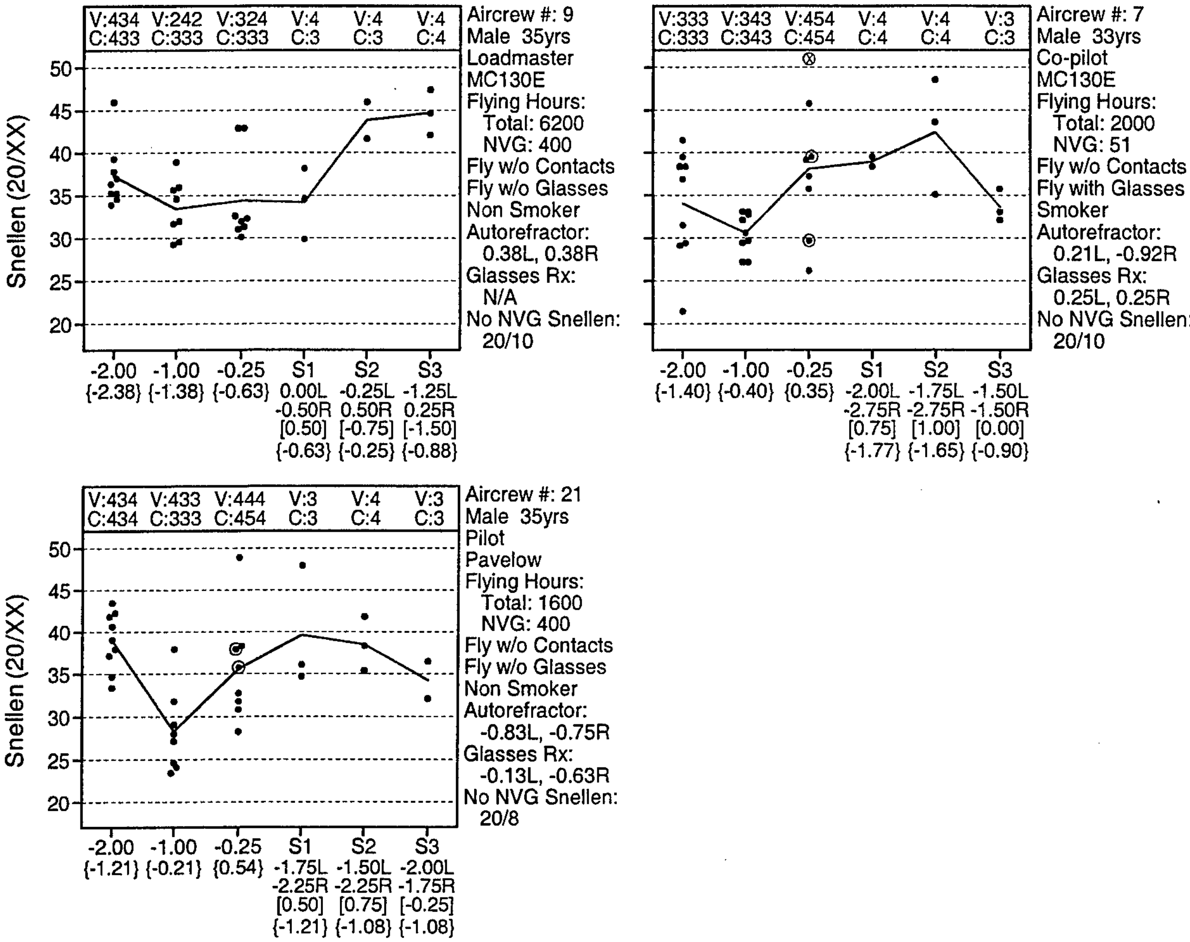
X = greater than 50 O = much worse than personal [ ] = left - right eyepiece { } = accommodative demand

Figure 6 (cont). Individual results. On the right side of each individual graph are demographic data, autorefraction and spectacle Rx when available, and visual acuity without NVG. Above are subjective ratings where V is visual focus clarity and C is comfort. Any rating of 5 (much worse than personal flying eyepiece setting) has the data point circled. Data points are all NVG visual acuities in Snellen notation for the three user-selected eyepiece settings (S1, S2, S3) and the three fixed settings. Below the eyepiece diopter settings are the difference in left and right settings [ ] and the calculated "net" setting, or accommodative demand, based on autorefraction data { }. The bold line tracks the mean NVG VA for each setting. Subjects sorted as Figure 5.



X = greater than 50 O = much worse than personal [ ] = left - right eyepiece { } = accommodative demand

Figure 6 (cont). Individual results. On the right side of each individual graph are demographic data, autorefraction and spectacle Rx when available, and visual acuity without NVG. Above are subjective ratings where V is visual focus clarity and C is comfort. Any rating of 5 (much worse than personal flying eyepiece setting) has the data point circled. Data points are all NVG visual acuities in Snellen notation for the three user-selected eyepiece settings (S1, S2, S3) and the three fixed settings. Below the eyepiece diopter settings are the difference in left and right settings [ ] and the calculated "net" setting, or accommodative demand, based on autorefraction data { }. The bold line tracks the mean NVG VA for each setting. Subjects sorted as Figure 5.



X = greater than 50   O = much worse than personal   [ ] = left - right eyepiece   { } = accommodative demand

Figure 6 (cont). Individual results. On the right side of each individual graph are demographic data, autorefraction and spectacle Rx when available, and visual acuity without NVG. Above are subjective ratings where V is visual focus clarity and C is comfort. Any rating of 5 (much worse than personal flying eyepiece setting) has the data point circled. Data points are all NVG visual acuities in Snellen notation for the three user-selected eyepiece settings (S1, S2, S3) and the three fixed settings. Below the eyepiece diopter settings are the difference in left and right settings [ ] and the calculated "net" setting, or accommodative demand, based on autorefraction data { }. The bold line tracks the mean NVG VA for each setting. Subjects sorted as Figure 5.

3.4.4 Aircrew number 19. Like aircrew number 1 this subject also consistently user-selected right and left settings that differed by 1 diopter. His subjective ratings were also better with his user-selected settings. Although his NVG VA was good with the fixed -1D, his ratings of visual clarity and comfort were both one step worse than for his user-selected settings. It is not clear why he selected different right and left settings. The autorefraction Rx was nearly equal in the two eyes. There was no eye examination data in his medical record. We predict that a full eye exam would reveal some difference in the two eyes. If so, he might select different settings for the PNVG.

3.4.5 Aircrew number 13. This 33 year old pilot had the most negative power user-selected settings of all subjects, where he selected -3.5D with S2 and S3, and consistently selected at least -2.5D for each eye. The calculated net settings were about -2.5D (average right and left). He rated all three runs of his user-selected settings as "5" much worse than the way he normally flies. Although mean NVG visual acuities were all about the same, his best ratings were with the fixed -1D (net -0.46D). Note that he appears to have among the most variable NVG VA of any subject. Aircrew are known to inexplicably select high negative lenses when asked to focus their NVG[2,3] in a squadron NVG preflight area

such as the Life Support Section. We suspect he would refocus his NVG downward toward -1D just prior to or during actual flight.

3.4.6 Aircrew number 20. This 41 year old pilot had one user-selected setting with good NVG acuity and ratings (S3) and two with poor acuity and ratings (S1, S2). The poor acuity and ratings with S1 and S2 are probably due to inappropriately selecting settings that are too highly negative and have too much difference between the left and right eyes. This highlights previously documented inconsistencies in focusing NVGs using the Hoffman 20/20 unit[1,2,3]. NVG VA was best with net eyepiece settings between -0.54D and -1.29D. Aircrew numbers 8 and 11 also had poor ratings and/or acuity with one user-selected setting that had a large difference between the two eyes.

4. DISCUSSION

Most of the aircrew members in this study would probably have good NVG VA and comfort flying with a PNVG with the standard fixed -1 diopter lenses in each eyepiece. Assuming aircrew number 14 wore glasses for flying, only aircrew number 10 had poor NVG VA with a fixed -1D, and an additional subject, aircrew number 19, had a subjective rating where the -1D was worse than the user-selected setting. One additional subject, aircrew number 1 would probably require a custom set of accessory snap-on lenses with different settings for each eye while using the PNVG. Therefore, Based on NVG visual acuity 20 of the 21 subjects, or 95%, would probably function well in training or operational environments with the standard fixed eyepiece setting of -1D. Based on NVG visual acuity, subjective ratings, and the need for different settings in each eye, 18 of the 21 subjects (86%) would probably be able to fly with the standard lenses. Current plans for production of the PNVG include issuing a set of accessory snap-on lenses with 20 pairs of lenses ranging from +1D to -4D. Results from this study indicate such a large set of accessory snap-on lenses is not necessary, and a smaller set would be adequate, with the availability of custom lenses if needed. Additional findings that require further investigation include inconsistencies in selecting the eyepiece focus, which sometimes results in poor NVG VA. Perhaps currently taught USAF focus techniques need to be reviewed and a new method developed. For example, McLean and van de Pol[13] showed that a binocular focusing procedure reduced the average eyepiece setting from -1.12D to -0.28D in subjects under 30 years old. We are designing research projects to address these issues.

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